comprising such works as, from their rarity or value, should not be lent out, all unbound periodicals, and such text-books as ought to be found in a library of reference, except when required by Committees of the Institute, or by Members or holders of second class stock, who have obtained the sanction of the Committee. The second class shall include those books intended for circulation.

ARTICLE VI.--The Secretary shall have authority to loan to Members and to holders of second class stock, any work belonging to the SECOND CLASS, subject to the following regulations:

Section 1.—No individual shall be permitted to have more than *two books* out at one time, without a written permission, signed by at least two members of the Library Committee; nor shall a book be kept out more than TWO WEEKS; but if no one has applied for it, the former borrower may renew the loan. Should any person have applied for it, the latter shall have the preference.

Section 2—A FINE OF TEN CENTS PER WEEK shall be exacted for the detention of a book beyond the limited time; and if a book be not returned within three months, it shall be deemed lost, and the borrower shall, in addition to his fines, forfeit its value.

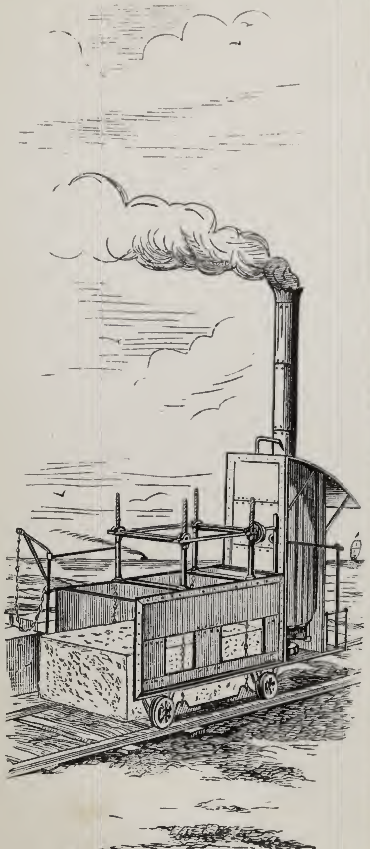
Section 3.—Should any book be returned injured, the borrower shall pay for the injury, or replace the book, as the Library Committee may direct; and if one or more books, belonging to a set or sets, be lost, the borrower shall replace them or make full restitution.

ARTICLE VII.—Any person removing from the Hall, without permission from the proper authorities, any book, newspaper, or other property in charge of the Library Committee, shall be reported to the Committee, who may inflict any fine not exceeding twenty-five dollars.

ARTICLE VIII.—No Member or holder of second class stock, whose annual contribution for the current year shall be unpaid, or who is in arrears for fines, shall be entitled to the privileges of the Library or Reading Room.

ARTICLE IX—If any member or holder of second class stock, shall refuse or neglect to comply with the foregoing rules, it shall be the duty of the Secretary to report him to the Committee on the Library.

ARTICLE X—Any Member or holder of second class stock, detected in mutilating the newspapers, pamphlets, or books belonging to the Institute, shall be deprived of his right of membership, and the name of the offender shall be made public.



TRAVELLING CRANE.

VIEW OF PORT SAID BREAKWATERS, SUEZ CANAL.

PORT SAID LIGHT HOUSE.

REPORT

ON THE

HYDRAULIC LIME OF TEIL,

TO

MESSRS. H. CHAMPIN AND GILLET,

SOLE REPRESENTATIVES AND AGENTS FOR NORTH AMERICA OF MM. L. & E. PAVIN DE LAFARGE AND SOULLIER & BRUNOT, THE ONLY MANUFACTURERS IN FRANCE,

9 NASSAU STREET, NEW YORK.

FABRICATION AND USE,

IN THE

CONSTRUCTION OF MARINE WORKS, CANALS, AQUEDUCTS, SEWERS, TUNNELS, RAILROADS, BRIDGES, BUILDINGS, FOUNDATIONS, FLOORS, ARTIFICIAL STONE, ETC., ETC.

BY

LEONARD F. BECKWITH,

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1873.

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PREFACE.

At the request of Messrs. H. Champin and Gillet, I have prepared, upon the Hydraulic Lime of Teil, the following observations, which are drawn from numerous reports upon the subject, from private sources, and from a personal knowledge of the value and applications of this lime.

LEONARD F. BECKWITH, C. E.

111 Broadway,
New York, *February*, 1873.

REPORT

ON THE

HYDRAULIC LIME OF TEIL.

FABRICATION OF TEIL HYDRAULIC LIME.

GENERAL DESCRIPTION.

Quarries.—The limestone quarries of Teil are situated on the banks of the River Rhone (Canton of Viviers, Department of Ardeche, France), and have been worked for several centuries. They produce a silicious hydraulic lime celebrated for its capacity to resist the destructive action of the sea. It is known in commerce under the name of *Hydraulic Lime of Teil.*

The quarries of Teil belong to the Lower Neocomian Marls of the Cretaceous Formation, and constitute the beds known to geologists under the name of *criocera limestones*, so-called from the resemblance of their fossil shells to a "ram's horn." These beds are worked by two companies, Messrs. Pavin de Lafarge, and Messrs. Soullier & Brunot. As the method of fabrication is the same in both companies a description of the works of the first will suffice.

The Lafarge quarries are opened on a length of 1,470 feet with an average height of 400 feet, and consist of three superposed layers of compact and homogeneous stone. The limestone is chiefly mined by the help of acid, which eats a cavity at the bottom of the drill hole and enables a heavier blast to be obtained.

The quantity of broken stone daily burnt averages 818 cubic yards, corresponding to a product of 500 tons of screened lime.

Burning.—The works, situated on the river bank at the foot of the quarries, contain 34 continuous lime kilns, which consume daily 100 tons of coal. Each kiln has a daily capacity of 130 cubic yards of lime. The heat at which the limestone is burnt is only sufficient to expel the carbonic acid and not to vitrify any part of the stone. The doors of the kilns open into vast sheds where the burnt lime goes through the process of slaking.

Slaking.—The slaking of hydraulic limes is always attended with difficulty, owing to the presence of lumps of burnt stone harder than the rest, and which cannot be slaked without previous crushing. These portions make a mortar of irregular consistency, and by slaking subsequently in the masonry might destroy it; moreover, danger attends the transportation of unslaked lime.

The above considerations have caused the general adoption of slaking hydraulic limes at the works. Formerly the slaking was done with a copious use of water; this practice has been discontinued, and slaking by sprinkling substituted. The burnt lime direct from the kilns, in thin layers, is lightly sprinkled with water, by a workman with a hose. The sprinkled lime falls into powder, is shovelled into heaps, and the slaking is completed by the help of the steam evolved, which penetrates the interstices of the mass. The lime remains in heaps about ten days; at the end of this time it is in sufficiently fine powder to be screened.

Screening.—The screens, similar to those used in flour mills, consist of sieves of No. 40 fine wire cloth, of 50 brass wires to a lineal inch. In the burning of lime, portions of the stone are imperfectly calcined; this arises either from the fire not reaching them, or from their peculiar chemical composition being unfavorable to burning at the low temperature employed. These unburnt portions are separated by a coarse sieve placed over the hopper of the shute leading to each screen. The burnt lime fully slaked in powder passes through the coarse sieve into each screen, from which it falls into a collecting chamber below. The bottom of this chamber, or flour-bin, consists of hoppers by which the lime is drawn off for packing.

The fine lime in powder, passing through the screen, leaves behind it numerous particles of the size of grains of sand. These particles are calcareous concretions, which do not contain sufficient free lime to become reduced to powder by slaking; they form in reality a natural cement which is a valuable addition to the hydraulic energy of the lime. The screenings are therefore collected and ground to powder, this operation being substituted for slaking, which was found to be impossible. A small elevator of sheet iron buckets on an endless chain returns the ground screenings to the screens, where their admixture with the slaked lime in powder coming from the kilns takes place uniformly and regularly. The grinding of the screenings keeps 19 pairs of grindstones constantly at work.

This method of slaking and screening Teil hydraulic lime at the works before delivery, has been practised since 1845. It is from this date that the use of Teil lime in powder spread rapidly throughout France.

Packing.—Teil hydraulic lime, slaked and screened ready for delivery, is a fine impalpable powder, and very homogeneous. It is usually packed in linen sacks of uniform size, which contain $110\frac{1}{4}$ pounds (50 kilogrammes) net weight of lime in powder. Uniformity in weight is obtained by a simple apparatus consisting of a suspended Beam Scales; the short arm holds the sack under the mouth of the hopper until, the weight of $110\frac{1}{4}$ pounds being reached, the beam descends; the packer closes the slide of the hopper, delivers the sack to be closed and sealed, and places another sack in its place. The sacks are closed and sealed with lead at the works, and the buyer is secured against fraud.

Packed in this way, Teil hydraulic lime has been shipped to a great distance by railroad and by sea, without suffering deterioration. For long voyages, however, a new method of packing it in barrels of 468 pounds net weight has been adopted. The barrels contain a lining or bag of thick gummed brown paper hermetically sealed, which preserves the lime during any length of time from alteration through absorption of carbonic acid and water from the air. Thick brown paper is an excellent non-conductor, and is air-tight.

Teil hydraulic lime is less liable than cements to alteration, as it depends chiefly for its hydraulic energy on silicate of lime, which after hydration contains 27 per cent. of its own weight of water.

One hundred pounds of Teil lime contain about 66 pounds of silicate of lime, which require 25.7 pounds of water for hydration; Teil lime in powder may thus absorb small quantities of water without much danger of alteration.

The establishment of Messrs. Pavin de Lafarge contains besides the 34 lime-kilns, 30 screens, 19 pairs of grindstones, 4 steam-engines, 1 water-wheel, and is well supplied with appliances such as tracks, docks, cranes and scales for handling lime. It employs 600 workmen and manufactures its own fire-brick, 2,000 tons annually, for the lime-kilns. The average yearly production is 100,000 tons of screened lime in powder. The size and completeness of these works enable the hydraulic lime to be manufactured on an extensive scale, and the product turned out is homogeneous and very uniform in composition.

COMPOSITION, STRENGTH, AND METHODS OF USING TEIL HYDRAULIC LIME.

Analyses.—Raw Teil Limestone analyzed by Professor Rivot, School of Mines, Paris, presents the following composition:

Lime	46.3
Oxide of Iron	0.7
Silica, Quartz Sand, and Clay	15.0
Carbonic Acid and Water	37.6

Teil limestone when dissolved in acid leaves an insoluble residue, varying from 12 to 17 per cent. of the total weight, and composed of free silica and quartz sand, with a very small quantity of clay. When analyzed this residue gives a constant proportion of 10 of silica to 1 of alumina; the clay, however, in its natural state is not attacked by chlorhydric acid.

The above analysis reveals the fact that a part of the silica is uncombined; though pulverulent, it is not easily dissolved by alkalies, as when Teil limestone is boiled with a diluted solution of $\frac{1}{10}$ of potash, only 1.87 per cent. of silica is dissolved; when the limestone is attacked by an acid, the silica remains as a muddy residue.

These characteristics indicate that Teil limestone belongs to the class of silicious hydraulic limestones.

After burning, Teil lime analysed by Professor Rivot gives the following composition:

Lime	78.29		73.60	
Oxide of Iron	traces		traces	
Silica	18.20	21.71	17.20	20.50
Alumina	1.80		1.70	
Quartz Sand	1.71		1.60	
Water and traces of Carbonic Acid	—		5.00	
	99.60		99.10	

Vicat gives the following analyses of Teil lime, containing a very small quantity of magnesia:

Lime	68.941		77.760	
Magnesia	0.612		0.541	
Silica	26.069	30.447	20.573	21.699
Alumina	4.378		1.126	
Peroxide of Iron	traces		traces	

The analyses show that Teil lime is very silicious and slow setting; it may be considered as the type of this variety of hydraulic limes, of which the mortars are remarkably durable in marine structures.

Theory of Concretion.—Silicious limes, like Teil hydraulic lime contain before burning, carbonate of lime, silica in fine sand, with a very small proportion of clay and oxide of iron.

By calcination at a low heat the carbonic acid is driven off, leaving an excess of quick-lime, with part of which the silica and alumina combine as silicate and aluminate of lime. The result is very uniformly:

70 to 80 per cent. of quick-lime;

30 to 20 per cent. of silicate of lime, with a small quantity of aluminate of lime, and uncombined quartz, intimately mixed.

$$CaO + Si\,O_3\ .\ 3\,Ca\,O + Al_2\,O_3\ .\ 3\,Ca\,O.$$

If the small quantity of alumina and iron is neglected, the composition of 100 lbs. of freshly burnt Teil lime is:

Silica	23
Lime	77

The 23 lbs. of silica are combined with 43 lbs. of lime, forming silicate of lime $SiO_3.\ 3\,CaO$

{ Silica	23
{ Combined lime	43
Free or quick-lime	34

When slaked by sprinkling, the quick-lime alone is hydrated, the silicates and aluminates remain anhydrous (Chatoney and Rivot). Practice shows that 14 lbs. of water are required to slake 100 lbs. of fresh Teil lime; in consequence of evaporation, only 10 to 11 lbs. of water remain, which is the requisite quantity for hydrating 34 lbs. of free lime.

The hydraulic energy of the lime is due to the anhydrous condition of the silicate and aluminate of lime, which, when the mortar is subsequently mixed, form hydrosilicates and hydroaluminates of lime by combining with 6 equivalents of water, and crystallize.

$$Ca\,O.HO.+Si\,O_3.3\,Ca\,O.6\,HO.+Al_2\,O_3.3\,Ca\,O.6\,HO.$$

A perfect setting of mortar is due to the *simultaneous* crystallization of the above elements, which grasps and binds the grains of sand and gives strength and hardness to the mortar.

The dampness which mortars throw off in setting, is due to the crystallization, which, in taking place, absorbs only the necessary number of equivalents of water, and rejects the surplus; the energy of setting is in proportion to the absence of an excess of water.

The hardness of the interior of a mortar is due to the hardness of the crystals and to the slowness of their formation. It is increased by the subsequent evaporation of the excess of water, and the absorption by the lime of carbonic acid from the air, producing an enveloping crust of carbonate of lime. This absorption, which slowly progresses from the exterior inwards, requires considerable time in which to act.

An imperfect setting is due to the presence in the mortar of substances which do not crystallize simultaneously, but irregularly, some later than others. Sulphates of lime and magnesia crystallize more slowly than the elements above mentioned, and are very destructive to mortars, as, by expanding at the moment of crystallization, they produce cracks and fissures.

Silicate and aluminate of magnesia crystallize slower than the same combinations of lime, and their presence in moderate proportions is injurious, and produces disintegration or inferior hardness in parts of the mass after the general setting has occurred. (Rivot.) In considerable proportions, however, as in Rosendale cements, it is probable that the silicate and aluminate of magnesia cause the entire mass to partake of the character of their slower crystallization, and their presence is not injurious. Both silicate and aluminate of magnesia are strongly hydraulic, and when alone they resist very successfully the action of sea water ; their value, however, in sea mortars in combination with silicate and aluminate of lime is questionable.

Unslaked particles of lime, which crystallize as hydrate of lime, subsequent to the setting of the mortar will swell and crack the mass. Sand and oxide of iron in lime act usually as inert substances.

A slow-setting hydraulic lime, such as Teil lime, crystallizes slowly, and produces well-defined and strong crystals; the slowness of setting is an additional guarantee against the disruption of mortar by the later crystallization of some of the elements. Quick-setting cements form a rapid and irregular crystallization of small crystals, and are, therefore, to be used with caution, where works of importance are undertaken.

To obtain a good mortar which will harden rapidly, it is essential to have the lime completely slaked, and to use only the quantity of water absolutely necessary to accomplish this in mixing. The latter should be very thorough, each particle of sand being coated with a thin envelope of lime.

An excess of either water or lime in proportion to sand is bad; the first makes a porous and friable mortar, and the second produces shrinkage, with loss of cohesion.

Weight of Teil Hydraulic Lime.—Teil hydraulic lime, slaked and screened, in powder, weighs per cubic foot, loose measure, 43¾ to 45 pounds. M. Noel, Director of the Arsenal Hydraulic Works, Toulon, gives as the weight of Teil lime, in powder, loose measure, 42½ to 43¾ lbs. per cubic foot. The weight per struck U. S. bushel, loose measure, is 54¼ to 56 pounds.

Tests of Strength.—The proportion of sand to lime has great influence upon the crushing and tensile strength of mortars. Numerous experiments with Teil mortars have been made by M. Pascal, Chief Engineer of the Works of the Port of Marseilles, and also by M. Noel, Director of the Hydraulic Works of the Naval Arsenal, Toulon (during the construction of three large graving docks, in which about 20,000 tons of Teil lime were employed, 1853 to 1865). The following tables are a summary of the tensile strength and crushing weight in pounds, per square inch, obtained in the above experiments with Teil mortars, after immersion in the sea during various lengths of time.

TABLE I.—(*Experiments of MM. Pascal and Noel.*)

TIME OF IMMERSION.	TENSILE STRENGTH IN POUNDS PER SQUARE INCH.				CRUSHING WEIGHT IN POUNDS PER SQUARE INCH.		
After 45 days....................	31.71	40.38	30.79	30.83.	219.59	191.75	194.09
" 90 "	85.06	88.49	83.78	77.68	359.62	362.41	355.20
" 180 "	97.11	106.22	89.16	86.88	593.98	467.13	451.34
" 1 year	123.43	111.63	126.42	122.15	612.91	591.84	561.87
" 2 years....................	141.06	164.20	......	......	613.88	577.33	573.92

TABLE II.—(*Experiments of M. Pascal.*)

Mortar of 3 parts of Teil lime to 5 of sand, in volume.

TIME OF IMMERSION.	TENSILE STRENGTH IN POUNDS PER SQUARE INCH.	TIME OF IMMERSION.	CRUSHING WEIGHT IN POUNDS PER SQUARE INCH.
After 3 months....	57.59	After 15 days	121.70
" 6 "	86.03	" 30 "	184.29
" 22 "	121.30	" 45 "	266.77

TABLE III.

Mortar composed of 564½ pounds of Teil lime per cubic yard of sand containing 33% of voids.

AGE OF MORTAR.	TENSILE STRENGTH IN POUNDS PER SQUARE INCH.	AGE OF MORTAR.	CRUSHING WEIGHT IN POUNDS PER SQUARE INCH.
45 days........	38.42	45 days........	205.04
90 "	83.77	90 "	259.15
180 "	94.86	180 "	504.24
1 year	120.94	1 year	588.99

In one instance a mortar composed of Teil lime and basaltic sand, after eight months immersion in the sea, acquired a tensile strength of 129.40 lbs. per square inch.

According to investigations made during the construction of the great Cherbourg Breakwater, the cohesive strength required in a mortar to withstand the battering action of the waves, should be about 29,500 lbs. per square yard, or 22¾ lbs. per square inch. The tables show conclusively that the mortars made with Teil lime have a greater strength than is required for masonry the most exposed to the sea.

Slaking and Mixing.—Teil lime unslaked, in lumps, weighs 36¼ lbs. per cubic foot. When slaked to a paste, the increase in volume is 0.35, and the increase in weight is 0.95.

Slaked and screened Teil lime in powder weighing $40\frac{3}{4}$ lbs. per cubic foot, made into paste, contracts in volume 0.41, with an increase in weight of 0.34.

The slaking of Teil quick-lime requires 14 lbs. of water per 100 lbs. of lime; subsequent evaporation leaves about 10 lbs., sometimes 7 lbs. of water remaining in one hundred of lime.

The hydration of 100 lbs. of Teil lime requires 28 lbs. of water; $1\frac{6}{10}$ cubic feet of lime paste containing 100 lbs. in powder will weigh, after taking, 128 lbs.

The taking of pure Teil hydraulic lime mortar occurs within 24 hours. After 18 hours the mortar sets strongly and will support the small Vicat needle, and in 24 hours the large needle. At the end of 48 hours it will support the Vicat drill with its full weight of $2\frac{1}{5}$ lbs. After the mortar has been immersed for 45 days in water 20 revolutions of the Vicat drill will penetrate to a depth of 0.0197 of an inch.

Hydraulic limes, in general, set too rapidly for the mortar paste to be prepared much in advance. Teil lime hardens rapidly, and if required to be used in paste, the mortar necessary for the day's work alone should be prepared. A preferable method is to mix the lime and sand dry in the desired proportions, and turn this dry mortar into paste as required. This method gives a more compact mortar with less water.

In mixing mortars, the importance of using as little water as possible, and making a perfect mixture by mechanical means, cannot be overestimated. In mixing Teil mortar salt and fresh water serve equally well.

When used for coating masonry, Teil hydraulic lime, like Portland cement, may be mixed the previous day, and re-mixed with additional water at the time of using it.

Proportions.—For one cubic yard of firm lime paste, 1,685 lbs. of Teil lime in powder are required, equivalent to 30 struck U. S. bushels, loose measure, of 56 lbs. per bushel. The proportion of lime per cubic yard of sand is regulated by the condition, that in good mortar the lime should fill the voids in the sand. The voids in loose damp sand vary from 0.31 to 0.35, and in compacted sand from 0.18 to 0.23 of the volume of sand.

With beton, the voids in the broken stone or pebbles vary from 0.35 to 0.40 of the volume, and the mortar should fill the voids.

For strictly impervious sea mortars made of fine and crumbling sands, in which the solidity depends solely upon the strength of the mortar, it is best to increase the proportion of Teil lime per cubic yard of sand to $10\frac{1}{2}$ bushels, instead of 9 bushels, the usual quantity. With silicious or basaltic sands of average size this increase is unnecessary.

In fresh water the proportion of Teil lime has been successfully reduced to 253 lbs. per cubic yard of beton by Mr. Desplaces, Chief-Engineer of the Paris-Lyons-Mediterranean R. R. The best proportions for Teil *mortars* for various uses are the following ones, which fulfil the conditions previously mentioned. (The struck U. S. bushel of Teil lime in powder, loose measure, is taken at 56 lbs.)

For Mortars in Salt Water: (Beton under water.) $10\frac{1}{2}$ U. S. bushels of Teil lime (590 lbs.) per cubic yard of sand, equivalent to 1 scant measure of lime to 2 full measures of sand.

For Mortars in Fresh Water: 9 U. S. bushels of Teil lime (506 lbs.) per cubic yard of sand, equivalent to $1\frac{1}{4}$ measures of lime to 3 measures of sand, making $1\frac{1}{10}$ cubic yards of stiff mortar paste.

For Mortars exposed to Air: $7\frac{1}{2}$ U. S. bushels of Teil lime (421 lbs.) per cubic yard of sand, equivalent to 1 measure of lime to 3 measures of sand.

For **Betons** the usual proportions of mortar and broken stone are:

In salt water	2 measures of mortar	to	3 of	broken stone.
In fresh water..............	1 do.	do.	2	do.
Artificial blocks	1 do.	do.	2 of	pebbles.

The above proportions for Teil mortars and betons are adopted by the French Engineers of Bridges and Highways and by the Engineers of the Railroad Companies, in their specifications and contracts. The proportions are sanctioned by successful practice, and although it may be found best to vary them in different localities of the United States, according to the sand and water used, and other circumstances, the variations will probably be slight. These proportions show the advantages attending the use of Teil lime, which produces a strong mortar with a smaller weight of lime, than that of Portland Cement, generally employed for the same purposes. Teil hydraulic lime does not require special workmen, and unpractised laborers cannot fail to make good work with it.

APPLICATIONS OF TEIL HYDRAULIC LIME.
MARINE STRUCTURES.

Investigations.—The causes of the destruction of mortars by sea water have been made the subject of investigation in different countries. The length of time required before the results of experiments extending over a number of years could be obtained, has rendered progress slow. By the aid of analysis chemistry has ascertained the elements of limes and mortars, and the changes which they undergo in the various stages of manufacture and use. The comparison of these results with those obtained by the analysis of mortars which have withstood for years the destructive action of sea-water, has elicited a few general laws which govern the formation of hydraulic mortars, and which have removed to a great extent the obscurity which enveloped the subject. It is to Vicat and later to Berthier, Chatoney and Rivot, that the success of these investigations, and the important results which have followed them, are chiefly due.

Action of Sea-water on Mortars.—The action of salt water on mortars immersed in the sea, may briefly be stated as follows.

Sea water, constantly washing against mortar and renewing the surfaces in contact, slowly dissolves the hydrate of lime which has not had time to become carbonated. As this action continues, the hydrate of lime disappears, and by leaving the mortar porous, hastens the action of the salt water on the other elements. The aluminate and silicate of lime, remaining in contact with water holding in solution chloride of sodium (common salt), salts of magnesia, and carbonic acid, become decomposed in turn.

The aluminate of lime is first decomposed, forming aluminate of magnesia and lime, both of which disappear. The carbonic acid in the sea water then attacks the lime of the silicate of lime, producing carbonate of lime, which, as fast as it forms, is dissolved in the excess of water surrounding it. The silica alone remains in a pasty state, and the mortar crumbles away.

When, on the contrary, the mortar has had time to become carbonated by the free hydrate of lime absorbing carbonic acid from the air and water, and forming an impervious protecting shield to the mass, and when hydraulic limes derived from silicious limestones are employed instead of limes from argillaceous (aluminous) limestones, then the mortar will not be destroyed. The aluminates, which are the first elements to become decomposed, either do not exist at all in silicious limes, or else in very small quantities. The mortar no longer rendered porous will resist the action of the sea.

Vicat, Chatoney, and Rivot concluded from their investigations that the chief element of hydraulic energy in a lime is the presence of silicate of lime. The presence of alumina in limes and cements hastens the setting, but is no guarantee of durability, as it forms combinations with lime, which, as mentioned above, do not resist as well as silicates the action of salt water.

A careful examination of the mortars which have most successfully resisted the destructive action of the sea, disclosed the fact that they contained hydrosilicate of lime to the extent of 25 per cent. of the volume of the mortar. The greater the proportion of this element in a mortar, the greater will be its durability.

Teil hydraulic lime is a silicious lime, containing 66 per cent. of silicate of lime, a very small proportion of alumina, and a sufficient quantity of uncombined lime to form the protecting envelope of carbonate of lime, which is an important element for the preservation of mortars. Teil lime fulfils the requirements mentioned previously as necessary in sea-mortars.

It was first employed in marine structures in 1832, since which time its use has steadily increased. Teil lime formed one of the starting points in the investigations of Vicat, Chatoney, and Rivot, and the results stated in their reports justify their high opinion of its value for sea-mortars.

Comparison between Teil Lime and Cements.—A comparative examination of the elements of Teil hydraulic lime and of slow and quick-setting cements will be found interesting.

Table IV. gives the composition, by weight, of the elements of hydraulic energy in limes and cements :

TABLE IV.

Silicate of lime..............	$SiO_3 . 3\,CaO$.	Silica.........	23
		Lime........	43
Silicate of alumina..........	$2\,SiO_3 . Al_2O_3$.	Silica.........	30
		Alumina.....	17
Aluminate of lime...........	$Al_2O_3 . 3\,CaO$.	Alumina	17
		Lime	28
Double silicate of lime and alumina	$SiO_3 .(Al_2\,O_3 + CaO)_3$	Silica.........	15
		Alumina.....	51
		Lime	28
Silicate of magnesia.........	$SiO_3 . 3\,MgO$.	Silica.........	23
		Magnesia	30

The method of manufacture strongly influences the composition of limes and cements. At a high temperature, silicate of lime and the double silicate of lime and alumina are formed. At a low heat, the double silicate is not formed, and the alumina, acting towards the lime the part of an acid, produces aluminate of lime. By the first method, slow-setting cements, such as English, and Boulogne

Portland cements are manufactured ; by the second method quick-setting cements, such as Vassy, etc., are produced.

On these facts as a basis, Table V. has been deduced in round numbers from the analyses of various cements, and is extracted from a Notice on the Hydraulic Lime of Teil, published in 1872.

Boulogne Portland cement may serve as an example of the method by which the table has been constructed. The analysis of this cement by Delesse, gives in one thousand parts :

Lime	651
Silica	204
Alumina	138
Magnesia	5.8

The fabrication is made at a high temperature ; the double silicate of lime and alumina is first formed ; 138 parts of alumina take up 40.24 parts of silica, the whole combining with 75 of lime, and forming 253.24 of double silicate of lime and alumina. There remain 163.76 of silica and 576 of lime. In the simple silicate of lime which is next formed, 163.76 of silica takes up 304 of lime, producing 467.67 of simple silicate of lime. Neglecting the small proportion of magnesia (5.8 parts in 1,000), there remain 273 parts of uncombined lime.

The composition of Boulogne Portland cement is then :

253 parts double silicate of lime and alumina.
467 parts simple silicate of lime.
273 parts free uncombined lime.

A similar calculation has been made in each instance.

TABLE V.

CEMENTS.	Double Silicate of Lime and Alumina.	Simple Silicate of Lime.	Aluminate of Lime.	Free Lime.	Free Silica.	Silicate of Magnesia.	Plaster (Sulphate of Lime).	REMARKS.
English Portland .	238	506	0	295	0	0	0	Resist the action of sea-water. Slow-setting cements obtained at a very high heat.
Boulogne Portland	253	467	0	273	0	0	0	
Boulogne Ordinary	169	606	0	58	0	0	0	
Vitry (burnt)	201	540	0	198	0	0	0	
St. Malo	123	680	0	0	0	0	0	
Moissac	367	528	0	0	40	332	21	Do not resist the action of sea-water.
Porte de France ..	360	493	0	129	0	0	33	
Antony	146	791	0	0	18	0	40	
Fagnerès..........	273	450	0	0	263	0	12	
Vassy..............	0	545	349	6	0	37	0	None of these cements resist the action of sea-water. Quick-setting cements obtained at an ordinary heat.
Porte de France ..	0	415	470	0	65	0	33	
Grenoble....	0	415	470	9	65	0	33	
Champ Rond.....	0	430	450	0	114	0	0	
Corbigny	0	488	370	0	75	0	44	
Vitry	0	634	291	26	0	0	0	
Gap	0	513	314	0	168	9	30	
La Valentine	0	545	349	6	0	37	0	
Teil hyd. lime ...	0	660	0	250	0	0	0	Resists sea-water.

A reference to the Table shows the large proportion of silicate of lime contained in Teil hydraulic lime, and explains the durability of Teil mortars, and their constantly increasing use. Teil lime is richer in silicate of lime than Portland or any cements of the Table. The proportions of aluminate of lime and silicate of magnesia in Teil lime are so small that they have been left out of the Table.

Action of Sea-water on Teil lime.—The action of sea-water on mortars varies in different seas, owing to variation in the proportions of destructive salts and gases contained in the sea. It is important to examine how Teil hydraulic lime in different localities, has stood the test of this action, and particularly that of salts of magnesia and carbonic acid.

Action of Salts of Magnesia.—Salts of magnesia are generally admitted to be the most destructive cause of decomposition in sea-mortars, although Rivot considers their action to be much exaggerated. Vicat in his experiments on hydraulic limes and cements employed a bath of sulphate of magnesia to test their durability. Table VI., by Vicat, gives the analysis of sea-water at different points.

TABLE VI.—(*Vicat.*)

SUBSTANCES CONTAINED IN 1000 PARTS OF WATER IN WEIGHT.	NEAR BAYONNE (ATLANTIC)	MEDITERRANEAN SEA.		NORTH ATLANTIC.	BRITISH CHANNEL.
Hydrochlorate of soda......	25.10	25.10	27.22	26.60	27.06
Sulphate of magnesia.......	5.78	6.25	7.02	"	2.29
Hydrochlorate of magnesia..	3.50	5.25	6.14	5.15	3.66
Sulphate of lime...........	0.15	0.15	0.10	0.15	1.41
Sulphate of soda...........	"	"	"	4.66	"
Hydrochlorate of potash....	"	"	0.01	1.23	0.76
Hydrochlorate of lime......	"	"	"	"	"
Carbonate of lime..........	0.20	0.15	0.20	"	0.03
Carbonic acid..............	0.23	0.11	Traces	"	Traces

TABLE VII.—(*Prof. Wolcott Gibbs.*)

(All sp. gr. refer to that of pure water at temperature of 14°C.)

LOCALITY.	DISTANCE BELOW SURFACE.	SPECIFIC GRAVITY.	SP. GR. AT TEMP. OF	SALINE MATTER PER CENT.	TEMP. F.	
					WATER.	AIR.
Washington Heights, H.R..	5′	1.0126	15°.25 C.	1.702	..	..
do.	6″	1.0111	15°.5 C.	1.585	30°	31°
Pier 1, Hudson River.....	1′	1.0182	15°.2 C.	2.348	34½	36½
do.	5′	1.0192	18° C.	2.533	..	..
do.	1′	1.0183	15° C.	2.351	..	..
East River, foot 17th St....	5′	1.0185	16° C.	2.461	31	31½
do.	1′	1.0178	14° C.	2.463	31	31½
Buttermilk Channel	5′	1.0155	16° C.	2.132	35	41½
Vanderbilt Landing, S. I...	5′	1.0188	10° C.	2.533	..	..
do.	1′	1.0205	15°.5 C.	2.706	33	39½
Mouth Navesink River, N.J.	5′	1.0177	15° C.	2.513	33	33

Table VI. shows that the proportion of salts of magnesia is considerably greater in the Mediterranean than in the Atlantic Ocean and English Channel. As Teil hydraulic lime has been successfully employed in the Mediterranean for upwards of 40 years in marine structures, it is a fair inference to conclude that in the Atlantic Ocean this lime would give even better results, being exposed to a smaller proportion of magnesian salts. The artificial blocks made with Teil hydraulic lime at Cherbourg, the works at St. Malo, built upwards of fifteen years ago, and the large quay walls and docks of Bordeaux, which are being constructed with Teil lime, prove that in practice it resists equally well the action of the waters of the ocean and of the Mediterranean.

Table VII. derived from the U. S. Coast Survey Reports (1856), gives analyses of sea-water in the Harbor of New York. It shows that the proportion of saline matter is very similar on both sides of the Atlantic Ocean, and it is safe to presume that Teil lime will stand the test equally well here. A warm temperature of sea-water, such as exists in the Mediterranean, though favorable to the use of hydraulic mortars and beton at the time of formation, is unfavorable subsequently, and tends to facilitate decomposition in the sea.

Action of Carbonic Acid.—With regard to the action of carbonic acid on sea mortars, it is maintained by Vicat, Chatoney, and Rivot, that its presence in sea-water in a certain proportion is beneficial for the preservation of mortars, a crust of carbonate of lime being formed. This envelope is essential for the preservation of a mortar, and hydraulic limes and cements which do not contain free lime capable of absorbing carbonic acid, and thus forming carbonate of lime, should be used with caution. An excess, however, of carbonic acid in sea-water is a disadvantage. As was mentioned previously in treating of the action of sea-water on mortars, lime has a stronger affinity for carbonic acid than it has either for silica or alumina. The decomposition of the silicate, and particularly of the aluminate of lime is to be feared in waters highly charged with carbonic acid, and hydraulic limes and cements containing alumina in considerable quantity are in greater danger of destruction from this cause than silicious limes, such as Teil hydraulic lime.

The proportion of carbonic acid in the Mediterranean is variable; abundant in some localities, entirely deficient in others. Admitting that wherever Teil hydraulic lime has been employed in that sea, carbonic acid exists in considerable quantities, it is easy to ascertain the amount absorbed.

Chatoney and Rivot analyzed numerous samples of Teil hydraulic lime from blocks immersed in the sea at Marseilles. The analyses prove that the surfaces of the blocks had absorbed from the air and water at least 0.03, and sometimes as high as 0.14 of carbonic acid, the centre of the blocks absorbing only from 0.01 to 0.05. As the blocks were all in a state of perfect preservation, the minimum of surface absorption 0.03 was sufficient to preserve the interior; this gives 0.02 as the average minimum absorption requisite for preservation. The total quantity of lime being 0.35, the absorption of carbonic acid necessary for protection would be 21 lbs. per cubic yard of beton, containing 296 lbs. of lime.

To solve the question, as to whether Teil hydraulic lime would be able to form in the Atlantic Ocean or the British Channel, its protecting crust of carbonate of lime, it is necessary to examine what has occurred in mortars, in localities where the carbonic acid is in small quantities; at several points on the western coast of France, Bayonne, etc., on the ocean, the proportion of carbonic acid is even greater than in the Mediterranean. In the analysis of beton blocks of Portland cement immersed in the British Channel, Rivot found that they had absorbed 0.017 of carbonic acid to 0.23 of lime. In a cubic yard of beton were 556 lbs. of cement, containing 494 lbs. of lime, which absorbed 37 lbs. of carbonic acid. Supposing this figure to be reduced one-half, to account for the lesser interior absorption, a minimum of 18½ lbs. is obtained, which is nearly the amount of carbonic acid found necessary for the protection of Teil lime in the Mediterranean. It is safe, then, to conclude that on the Atlantic coast of France, Teil lime will find sufficient carbonic acid for its protection, and it is presumable that the same will be the case on the Atlantic coast of the United States.

Plants and Shells.—The growth of marine plants, and the deposits of marine shells and incrustations on the surfaces of sea mortars and masonry, form the most efficacious protection that could be devised.

Storms and Currents.—Storms and sea currents disintegrate mortars by mechanical action; as Teil lime has successfully resisted these causes of destruction in the Mediterranean, no special danger from their action need be feared in other localities.

Tides.—Tides are an advantage in the construction of marine works, and admit of part of the masonry being built dry at low tide; this allows some time for mortars to set, and for their elements to complete all chemical reactions, which if they occurred after the setting would destroy the work. Slow-setting cements requiring from 8 to 18 hours to set are usually preferred in marine structures, but they are subject to the same inconvenience as Teil lime, in being covered by the tide before the setting is completed, unless special precautions be taken to protect the mortar or beton by a coating of quick-setting cement, or some other device. Teil hydraulic mortar sets strongly in 18 to 24 hours, and if it takes longer than some cements, its hardness once set rapidly equals theirs.

Teil hydraulic lime has been employed in the Mediterranean for all kinds of marine structures, in artificial blocks of beton dried during several months previous to immersion, and in beton immediately immersed in the sea for foundations. These betons have been equally durable, and there is no reason that it should be otherwise in tidal seas, where in any case precautions against washing away by the ebb and flood have to be provided, and where the temporary retreat of the sea renders the work of construction easier. The action of tidal currents on mortars is not different from that of river currents, in which Teil lime is daily employed in submarine works.

Economy of Teil Lime compared with Cements.—There remains the question of economy to be considered with regard to the use of Teil hydraulic lime instead of cements, such as Portland and others.

The claim for economy is based with justice upon two points: the comparative weights of Teil lime and cements, which are respectively about 1,200 pounds and 2,100 pounds per cubic yard, and the greater richness in silicate of lime, of Teil lime over an equal weight of cement.

For good sea mortars two conditions require to be fulfilled: *first*, each grain of sand should be coated with lime, and the voids filled; *second*, the proportion of silicate of lime, the most desirable element in hydraulic mortars, should not fall below a minimum quantity.

Chatoney and Rivot, in their examination of betons which had best resisted the action of the sea at Marseilles, found that 25 per cent. of the volume of the mortar was hydrosilicate of lime. This quantity, however, is not obligatory, as the hydraulic mortar used at Marseilles, in building the Napoleon Port, was 598 lbs. of Teil lime per cubic yard of sand, which corresponds to a proportion of 22 per cent. in volume of hydrosilicate of lime, and has given excellent results.

In hydraulic mortars, made either with Teil lime or Portland cement, the volume of lime or cement required to coat the grains of sand and fill the voids is equal in both cases. Owing to the greater density of Portland cement the weight required of the latter for the above volume will be greater, and per cubic yard of mortar will be about:

1,068 lbs. Portland cement (White Bros.)
1,070 " Boulogne Portland (Demarle.)
1011 " London Portland cement.

Whereas the same volume of Teil lime weighs 590 to 600 lbs. and works well in practice. If equal weights are employed instead of equal volumes, then the Portland cement will be only about one-half of what is required to fill the voids of the mortar.

With regard to the comparative richness in hydrosilicate of lime, of Teil lime and Portland cement mortars, by applying to the analyses of the latter the formulas of Chatoney and Rivot for hydration of silicates and aluminates of lime, and supposing the reactions completed, the following composition is obtained:

	English Portland.		Boulogne Portland.
Silicate of lime	60.3	....	58.5
Aluminate of lime	23.9	....	36.5
Free lime	14.9	....	4.3

Teil lime according to the same authorities contains on an average 66 per cent. of silicate of lime and 25 per cent. of free lime. This richness in silicate of lime gives Teil lime an advantage in any mortar for which a definite volume of lime or cement is required, and at an equal price per pound the economy of using the lesser weight per cubic yard of sand is clear.

If the quantity of silicate of lime is required to be equal in mortars made either with Teil lime or Portland cement, the weight of Teil lime will be considerably less than that of cement. Theory requires 598 lbs. of Teil lime to fill completely the voids of a cubic yard of sand; this weight contains 395 lbs. of silicate of lime. The weight required of Boulogne Portland cement, one of the best of slow-setting cements, to furnish an equal weight of silicate of lime is 674 lbs., which represents a volume of cement only $\frac{2}{3}$ of that required by theory for filling the voids of a cubic yard of sand.

These considerations show clearly that to make the employment of Teil lime and Portland cement equally economical, the latter must be lower in price than the former, or else the weight of Portland cement per cubic yard of mortar must be considerably diminished below that which would best fulfil the requisite conditions for good mortars.

The following comparative proportions are frequently employed of Teil lime and Portland cement for hydraulic mortars and betons.

Portland Cement.	Mortar:	cement ....840 lbs.	
		sand............$\frac{9}{10}$ cubic yards.	
	Beton:	broken stone 1	"
		mortar ....$\frac{1}{2}$	"
Teil Hydraulic Lime. (Marseilles.)	Mortar:	lime............590 lbs.	
		sand ....$\frac{9}{10}$ cubic yards.	
	Beton:	broken stone..0.93	"
		mortar.........0.58	"

The economy in the usual proportion of Teil lime instead of Portland cement is 250 lbs. per cubic yard of mortar, and admitting the same proportions of one of mortar to two of broken stone (which are often employed) for beton, the economy is 125 lbs. per cubic yard of beton. The saving may thus amount to 30 or 40 per cent.

Use of Teil Lime in Seaports, &c.—Teil hydraulic lime is now used in a large number of seaports. At the Universal Exhibition of 1867 specimens of Teil hydraulic mortars and betons in excellent preservation were exhibited from 22 seaports.

The chief ports where it is employed are: Marseilles (where in marine structures costing upwards of 50,000,000 francs Teil lime has been exclusively used), Toulon, Cette, Bordeaux, St. Malo, Cherbourg, Barcelona, Corsica, Algiers, Bona, Oran, Tunis, Genoa, La Spezzia, Trieste, Constantinople, Odessa, Suez and Port Said (120,000 tons of Teil lime), Alexandria Harbor Works (175,-000 tons). It is also exported to La Plata, Rio Janeiro, Saigon, &c.

The following details respecting works in various ports, built of Teil lime, will be of interest.

Marseilles.—Teil hydraulic lime has been almost exclusively used at Marseilles during the last thirty-four years, by M. Pascal, the Chief Engineer, in the construction of the basins of La Joliette, Frioul, Napoleon, and the basins of the Marseilles docks and ware-houses. It was employed as concrete for foundations and for artificial blocks for the protection of the seaward slopes of the break-waters. The beton blocks were made in moulds and allowed to harden by exposure to the air for three months previous to immersion. The volume of each block was 353 cubic feet, with a weight of about 22 tons. The dimensions were $11' \times 5' \times 6\frac{1}{2}'$, and two grooves for suspension chains ran across the bottom. The composition of the mortar for concrete blocks was :

Teil lime in powder	3 parts in volume.
Sand	5 " "

The concrete was made of one volume of mortar mixed with two volumes of broken stone.

In concrete for immediate immersion, two volumes of mortar to three of broken stone were used.

M. Pascal considered that good hydraulic lime, for sea-mortars and concretes, was preferable to any mixture of lime and pozzuolana (sometimes added to hasten the setting), of lime and cements, or of natural and artificial cements.

For good work, sufficient time should be allowed for blocks to harden before immersion, and obtain their protecting crust of carbonate of lime.

The system of building quay walls at Marseilles, with blocks of

Teil concrete, was very successful. A bed of broken stone or gravel was formed on which four courses of artificial blocks were placed, their greatest length inwards forming the thickness of the wall (11 feet); the top course was 8 inches above the level of low tide. Divers were required to place the blocks which broke joints as in ordinary masonry. To guard against future settling when the masonry wall would be built on the blocks, the latter were temporarily loaded with two courses of similar blocks, which were removed when the settling was completed to the level of low tide. The blocks were of the volume, weight and composition previously mentioned. (Plate I.)

The construction of concrete blocks for the quay walls and breakwaters of Marseilles, required the establishment of large yards, covering 375 acres for machinery, workshops, tracks, supplies, and space for one thousand blocks in every stage of completion. The yard turned out monthly 300 to 375 blocks.

Toulon.—Teil hydraulic lime was employed in the works of the Port of Toulon; notably for 200,000 cubic yards of beton used in the construction of the three large graving docks of Castigneau. M. Noel and M. Raoul, Chief Engineers, state that Teil lime has perfectly resisted the action of the sea at Toulon, and also at Port Vendres, where large blocks for the jetty were made of limestone masonry cemented with Teil hydraulic lime mortar.

Algiers.—Since 1852 Teil lime is used in this port mixed with sea sand, for concrete immersed green, and for artificial blocks, which are allowed to harden in air from 2½ to 5 months according to the season. Teil concrete has shown great strength and resists the action of the sea at Algiers and other points along the coast. (See Appendix.)

Port Said.—The successful creation by M. de Lesseps of the artificial harbor of Port Said at the entrance of the Suez Canal, enclosing 90 acres of sea room, and with the basins 130 acres, is due in a great measure to the use of Teil lime, which allowed the project to be carried out without an expenditure which would have curtailed its dimensions, and endangered its success.

The two jetties, starting from points on the shore 1,530 yards apart, run out to sea, and approach each other within four hundred and forty yards. The length of the Western jetty, built first, as a protection from the prevailing winds, is 3,390 yards, and that of the Eastern jetty is 1,968 yards. The jetties are about 28 yards wide at the base and 6 at the summit, with a height of 10 yards at their seaward extremity. The summit of the jetties rises 6½ feet above the mean level of the Mediterranean Sea, and their slopes are at 45°.

In their construction, about 120,000 tons of Teil hydraulic lime were employed, chiefly in the fabrication of 25,000 artificial blocks of the same dimensions as those used at Marseilles. The volume of each block was 353 cubic feet, and the weight about 25 tons. The blocks were composed of:

Teil hydraulic lime in powder, 548 pounds.

Sand of the desert (almost impalpable), 1 cubic yard.

The mortar was mixed with sea-water, and poured into moulds, and after 2 to 3 months hardening in the air, the blocks were ready for immersion.

The above proportions correspond to 1 volume of lime to 2 of sand. The yard of fabrication contained from 2,000 to 3,000 blocks in various stages of preparation, and turned out 900 blocks monthly, 30 daily for immersion, by tipping into the sea from barges. The contractors were Messrs. Dussaud Bros., celebrated for their important marine constructions at Algiers, Marseilles, Cherbourg. The contract price of the blocks was 42 francs per cubic metre or $6.40 per cubic yard. The cost of each block in its final position was 1,000 francs, or $15.30 per cubic yard. Teil hydraulic lime and desert sand were also used in similar proportions to those employed for the artificial blocks, in building the Lighthouse of Port Said. The latter is 180 feet high, constructed of a single mass of beton with no joints, and rests on a beton base of about 400 cubic yards. (See Frontispiece.)

Alexandria.—The Harbor Works of Alexandria, Egypt, are in course of construction, and use an immense quantity of Teil lime;

they consist of a breakwater about $1\frac{1}{2}$ miles long and an inner jetty, and quays; over 15,000 acres will be enclosed.

The breakwater will rise 10 to 15 feet above the mean level of the sea, and will be built on the Port Said plan, with artificial blocks. About 15,000 of these are made, and it is estimated that 35,000 blocks in all will be required, besides large quantities of rubble stone. The quantity of Teil lime used in this vast undertaking will be about 175,000 tons.

The concrete blocks are each 353 cubic feet in volume ($10' \times 6' \times 6'$) and about 20 tons in weight. Each block contains 34 cwt. of Teil hydraulic lime in powder mixed with desert sand and broken limestone ($291\frac{1}{4}$ lbs. lime per cubic yard of concrete).

The concrete is mixed by 10 H. P. machinery on the upper platform of a travelling crane, stationed over the empty mould, which is filled from above. After a few days the frame sides of the mould are removed, and the block is left to harden for $2\frac{1}{2}$ months. Forty blocks are ready daily and loaded on lighters, towed out to sea, and tipped on the site of the breakwater.

The yard of fabrication constantly contains about 2,500 blocks in course of preparation, in five long rows, running over nearly $1\frac{1}{4}$ miles of ground. It is well supplied with travelling cranes, 50 miles of railroad track, turn-tables, 12 locomotives, several hundred trucks, 40 steam engines, 12 lighters, six steamers, and one large steam derrick, representing about £200,000 sterling of capital, in plant alone. Two thousand Arabs are employed.

This undertaking, which equals in greatness that of Plymouth or Portland, will probably be completed in one-fifth the time. ("The Engineer.")

The contractors are Messrs. Greenfield & Co. (in reality Messrs. Kennard, Elliot & Maclean), Mr. May, Chief Engineer, and Mr. Brown, Chief Assistant Engineer.

General Observations.—Teil hydraulic lime has been exposed to the action of the sea for a long period of years, in some localities, since 1832, and there has been ample time and opportunity for any defects it may have to declare themselves. Far from this, Teil lime has uniformly given good results, and Vicat, Chatoney, and Rivot, speak of it in terms of high appreciation; the records in their reports show conclusively its remarkable durability in marine structures, and the Teil mortars examined are referred to as being in a state of excellent preservation.

It is considered preferable to use Teil lime alone in mortars or concretes, instead of in mixtures with other limes or cements, natural or artificial; pozzuolana is generally subject to great alteration in sea-water, and should be avoided in any case.

In June, 1856, M. Pascal, Chief Engineer at Marseilles, in a diving-bell, visited with the greatest care the Teil mortars and artificial blocks of the Port, chiefly the oldest, which were at a depth of 43 feet, and immersed from 7 to 9 years previously. His testimony is interesting; he says:

"The exterior blocks, the only ones I could see, are covered with a luxuriant vegetation, and their edges are perfectly sharp. An opening which I had occasion to make in the jetty, allowed me to visit a submerged block which did not show the slightest trace of vegetation, owing to the complete absence of light, and which was very hard and perfectly intact; the age of this block might be seven years. I also visited the concrete immediately immersed after fabrication about 7 or 8 years ago; this concrete was equally intact, but instead of a growth of marine plants, a thick deposit of 'serpules anhélides' was found. The thickness of these deposits runs up to 13¾ inches. Everywhere intact betons."

The great extension in the use of Teil lime for marine structures is chiefly due to the favorable results obtained in the works at Marseilles.

CANALS, SEWERS, AQUEDUCTS.

Teil hydraulic lime is used in the construction of the Forez Canal, France, and has given excellent results. (See Appendix.) It is very suitable for all kinds of work which require to be water-tight.

BRIDGES, RAILROADS, TUNNELS.

Teil lime has been used in large quantities for railroad constructions in France, and the engineers of several important roads speak highly of its value, in the most difficult parts of the works under their direction. (See Appendix.)

In the construction of the celebrated Mont Cenis Tunnel, upwards of 5,000 tons of Teil hydraulic lime were employed with very satisfactory results. (See Appendix.) It has been used in the construction of bridges, for the masonry of piers. At Constantine, in Algeria, the remarkable bridge of El-Kantara, with a span of 188¼ feet, has been built across a chasm 394 feet deep. The piers were built of limestone, cemented with Teil hydraulic lime; in the trial loading of the bridge, they were subjected during forty-eight hours, without showing any sign of weakness, to a crushing weight of 260 lbs. per square inch. During the construction of the piers, the temperature of the air was frequently 112° to 134° F. This heat would have destroyed by crumbling, many limes, but Teil mortar hardened rapidly under it and attained great strength.

WAREHOUSES, BUILDINGS, FOUNDATIONS, CELLARS.

Teil hydraulic mortar makes very good work in masonry for warehouses, buildings, etc., which, from their position, are subjected to more or less humidity. It makes an excellent coating instead of cement for masonry, and is particularly adapted to foundation work, cellars, cesspools, etc. Cornices of buildings are made of Teil lime.

ARTIFICIAL STONES.

In many localities artificial stones of various kinds are destined to a large consumption, from their cheapness as compared with stone brought from a distance, or ornamental cut stone for architectural purposes.

Beton Coignet, an artificial sandstone of great strength, is successfully used in all kinds of construction, from the carved work of a church window, to the foundations of a steam engine, a sewer, or an aqueduct. Teil lime has been employed in the fabrication of Beton Coignet, and experiments were made by M. Michelot, Engineer-in-Chief of the Ponts et Chaussées upon samples of the following composition:

Mixed sand	4 to 5	volumes.
Teil or other hydraulic lime	1	"
Portland cement	$\frac{1}{4}$ to $\frac{3}{4}$	"

The results were a tensile strength of 288 to 426 lbs. per square inch, and a crushing weight of 2,634 to 7,495 lbs. per square inch.

Paris contains upwards of 31 miles of sewers of various sizes made of Beton Coignet, and there can be no doubt that with Teil lime, this excellent material for sewers can be made at a saving of at least 20 per cent. on common masonry. The Fontainebleau section of the Vanne Aqueduct, constructed to furnish Paris with water, is 37 miles long, made of fine sand, hydraulic lime, and a small proportion of cement, and is an instance of what can be built with this beton, when good ingredients are used.

In the manufacture of other artificial stones such as the *Frear Stone* (shellac, hydraulic cement and sand), or the *American Building Block Co.'s Stone* (unslaked lime mixed with moist sand), it may be found advantageous to mix a proportion of Teil hydraulic lime with the other ingredients. Whenever the quality of the stone depends on the use of a strong hydraulic lime or cement, Teil lime will give good results.

BRICKS AND SLABS FOR FLOORS, PARTITION WALLS, ETC.

Bricks and slabs made of pulverized blast furnace slags, mixed with a small proportion of Teil hydraulic lime, make a very light and strong material, which does not conduct sound, and will stand a heat of 1,000° C. without melting. This material, pressed into various shapes, is suitable for deafening floors, and for partition walls, fire-proof buildings, etc. It is best to use slags containing as little sulphur as possible, as sulphate of lime is injurious to the mixture, and cracks and fissures it.

CONCLUSION.

The preceding remarks on the applications of Teil hydraulic lime show to what extent it is already used in the various departments of engineering and construction. It fills the want which is felt in many localities for a good hydraulic material, and the experience already obtained of its durability is the best guarantee for the future.

In the Appendix will be found a brief account of the method and cost of fabrication of the artificial blocks of Teil concrete employed at Marseilles, and a number of certificates from engineers who have used Teil hydraulic lime in their works..

APPENDIX.

FABRICATION OF ARTIFICIAL BLOCKS OF TEIL BETON AT MARSEILLES.

General Description of the Yard of Fabrication.—The plant consisted of a steam engine of 15-horse power, which set in motion:

1. The wheels of three mortar mills.
2. A balance beam for elevating the ingredients to the floor of the mills.
3. The mixing cylinders for beton.
4. An hydraulic wheel for raising water from a well to wash the pebbles previous to use.

The floors of the mortar mills and mixing cylinders for beton were raised above the level of the yard. The materials, loaded into cars at the heaps, were run by a rail track A (Plate II.), upon a platform B, under the balance beam, which lifted them to the floor above, where by another rail track, running parallel to the mortar mills, the cars reached the latter, and the sand and lime were emptied into them.

The water for mixing mortar was contained in large tubs, fixed to the floor, and supplied by pipes connecting with the city mains.

The mortar, having been mixed, was expelled from the mills through an aperture in the bottom of the trough, kept closed by a valve during the mixing, and fell into a special car, placed beneath the mill under the centre of the valve.

The car by the turn-table, C, and the lower rail track, D, was run upon the platform of the balance beam, and lifted to the floor of the mills, where the rail track, E, directed it to the small shutes, under which were stationed the mixing cylinders for beton,' with their covers open. The car was tipped, and its contents directed into the mixing cylinder by the shute.

The elevation of the mortar cars was followed by that of the pebble cars, arriving on the platform of the walking beam by the track D from the water wheel. The pebbles were emptied in the same way as the mortar, into the beton cylinders, which then contained the necessary ingredients for a mixing of beton.

The empty sand and lime cars were lowered to the yard on the platform of the steam balance beam, and, to avoid crowding, the empty mortar and pebble cars were lowered by a balance beam worked by a windlass, and situated at the opposite end of the floor.

The ingredients in the mixing cylinders were intermixed by the rotary motion communicated to each cylinder by a belt from a line of shafting.

When the mixing was completed the beton cylinder on its travelling frame was run by a short cross track upon a truck, which carried it by a lower rail track to the head of the line of blocks in fabrication. This line was formed by successive box moulds, upon the top of which was established a movable rail track. This track was continued onwards as the line of blocks progressed. The beton cylinder was run on the movable track over the mould to be filled, emptied of its contents, and run back to the mixing platform by the way it came. The size of the finished block was 3.40 metres long by 2.00 metres wide, and 1.50 metres high.

The beton having attained a sufficient degree of hardness, the blocks were fit for immersion. Longitudinal ties with rails were laid on the ground on each side of the line of blocks to be lifted; on this temporary track a travelling crane approached, lifted the block, and transported it to a truck running on a cross rail track F leading to the shipping wharf. A derrick lifted the block and deposited it on the deck of a lighter, which transferred it to the point of use. Some details of the methods of fabrication of the beton and handling will be useful.

Fabrication of the Mortar. Proportions.—The mortar was composed of 3 parts of screened lime in powder to 5 parts of sand, uncompacted, and corresponding in weight to 632 lbs. of lime per cubic yard of sand, which formed one mixing of mortar (300 kilog. lime to 0.80 cubic metre of sand; proportions used in the construction of La Joliette and Le Frioul ports).

Various sands were employed; pure sea-sand, pudding-stone sand, and quarry sand. The two latter qualities contained, as shown by washing, from 12 to 18 per cent. of foreign matter such as earths and clays.

In these conditions the quantity of water required for mixing the lime into paste varied with the quality of the sand; with sea-sand about 6 U. S. gallons of water per 100 lbs. of lime were used, and with earthy or clayey sand 9 to 9½ gallons were required.

The above proportions of mortar after mixing gave an increase in volume of:

5 per cent.	for mortar	made	with	sea-sand.
7	"	"	"	pudding-stone sand.
6	"	"	"	ravine or quarry sand.

The sand was measured in *iron cars* of the exact volume (0.80 cubic metre) required for one mixing of mortar. (Plate V.) The lime was in sacks sealed with lead, and of an average weight of 50 kilog. or 110¼lbs., and the necessary quantity of lime was obtained by taking a certain number of sacks without further weighing. The water was measured in buckets of known capacity.

On the ground floor of the mortar mill building were the rail-tracks and turn-tables for the handling of the cars, the steam engine, and the lines of shafting for setting in motion the mortar mills, the hydraulic wheel for washing the pebbles, and the beton cylinders. On the upper floor, which consisted of a platform raised 10½ feet above the ground and supported by timber posts, were established three mortar mills.

Each *mortar mill* (Plates III., IV.) consisted of a circular cast-iron trough of trapezoidal section in which revolved three wheels and a scraper, fastened to the ends of four axles at right angles to each other, and dividing the surface of the trough into quarters.

The wheels were placed at unequal distances from the centre of the mill, and in such a manner that the sum of their several widths of tire was equal to the width of the bottom of the trough; thus a wheel ran always tangent to each side of the trough, whilst the third wheel ran on the middle of the bottom.

The scraper was formed of three curved wings reaching to the bottom of the trough, and fixed above to a cross-bar of iron at the extremity of the fourth axle.

From a ring fastened above the iron bar, the hook of a sheet-iron scraper was suspended, at the end of each mixing, for cleaning the trough. The section of the sheet-iron scraper was equal to that of the trough, and by means of a handle a downward pressure was exerted on the scraper, to drive it into the mortar, and to force the latter over the opening of a trap-door in the bottom of the trough, kept closed during the mixing, and through which the mortar was expelled into a car below.

The rotary motion of the mortar mills was obtained by bevelled gearing on the horizontal main shaft driven by the steam engine, and on the vertical shafts, running through the centres of the mills, to which were fastened the axles of the wheels and scraper.

Each mill produced in one mixing 0.84 cubic metre (1.10 cubic yard) of mortar, and the time required was from 15 to 20 minutes. The three mills produced 17 cubic yards of mortar per hour. In the fabrication of the mortar, the lime was first emptied into the trough of the mill and equally spread out; sufficient water was added to form a soft paste, and the sand was then thrown in and the whole mixed. Fifty-nine gallons of water were generally used for one mixing.

The *iron cars* which received the mortar (Plate VII.) were subdivided into three equal compartments, each 0.28 cubic metre in volume (9.89 cubic feet), so that each car contained a full mixing of mortar, inclusive of the increase in volume of the latter.

Fabrication of the Beton and Blocks. Proportions.—The beton was composed of five volumes of broken stone and three volumes of mortar.

To obtain these proportions, the volume of a stone car was made 0.465 cubic metre (16.42 cubic feet), and its contents, when mixed with one of the compartments of a mortar car, 0.28 cubic metre, corresponded to 0.50 cubic metre of beton (17.66 cubic feet). The mixing of the broken stone and mortar was accomplished in six horizontal sheet-iron *cylinders* (Plate VIII.) rotating on their axes, and placed on four-wheeled trucks or travelling frames, for transportation on the rail tracks. The cylinders were placed on a floor beneath that of the mortar mills, at a height sufficient to allow of the ingredients for concrete being run into them by shutes or inclined planes from the upper floor. On the platform were six rail tracks, which ran across it.

The mortar car, from under the mortar mill, after being directed by the turn-table and the lower rail track to the elēvator, was lifted to the upper floor, and run upon a track which was laid adjoining the shutes, ten in number, leading to the beton cylinders. The mortar car was stopped in front of the first shute, into which the contents of one of the compartments were emptied, and thus directed into a beton cylinder below ; the contents of each of the other two compartments were emptied in the same way into the next two shutes leading to beton cylinders.

The elevation of a mortar car was followed by that of three cars filled with washed pebbles, which were in succession emptied into the beton cylinders which had received the mortar.

A second mortar car, followed by three cars of broken stone, were then lifted, and emptied in the same way; the filling of the six cylinders in use for mixing beton was thus completed.

After each filling, the empty cars were lowered to the yard and returned for a fresh supply of mortar, pebbles, and broken stone.

The pebble cars, when filled, were placed under the water spout connected with the water wheel, and the pebbles thoroughly washed.

The *cars* used in the transportation of these materials (Plate VI.), consisted of a box carried by a four-wheeled truck. The box was kept in equilibrium on a longitudinal axis, by means of a cross rod attached by rings to the bottom of the box. The rod ended in a hook at the front of the car, and kept closed one of the sides of the box; this side acted as a movable door hinged on its upper rim. At the back of the car the rod was ended by a hook catching on a peg fixed to the truck. By a sudden movement given to the rod, the equilibrium of the car was destroyed, the side door opened, and the contents emptied.

The mixing machines having been filled, a rotary motion was communicated to each cylinder by a belt passing around a small pulley on the axis of the cylinder, and a second pulley on an intermediate line of shafting which ran the whole length of the platform, and was driven by a cogged connection with the main shaft of the mortar mills. To put the mixing in operation, the beton cylinders were backed from the shutes sufficiently to tighten the belts on the pulleys, and then kept in position by blocking the wheels of the frames or trucks.

The volume of a mixing of beton, as previously settled, was to be 0.50 cubic metre (17.66 cub. ft.), and mixing cylinders of 0.75 cubic metre (26.49 cub. ft.) capacity were considered at first to be large enough; but it was found necessary to increase the volume of the mixing cylinders to 1.00 cubic metre (35.32 cub. ft.), in order to obtain sufficient room for the ingredients to intermix, by detaching themselves from the sides of the cylinder. The interior space of the cylinder was, moreover, divided by 12 radial arms riveted to the shaft and sides, for the purpose of more completely dividing and mixing the ingredients. (Plate VIII.) Twenty revolutions of the cylinders, at a moderate speed, were sufficient to effect a proper mixing of beton. The speed should be moderate, otherwise the ingredients, by virtue of the centrifugal force, would adhere to the sides of the cylinder without intermixing.

To regulate this part of the fabrication, which would be impossible if the number of revolutions had to be counted by the eye, a mechanical counter was provided. It consisted of a sheet-iron disc attached to the fixed frame of the mixing machine, and capable of revolving around a ring screw on its axis. The circumference of the disc was divided into 20 parts by triangular notches, thus forming an equal number of teeth less one which was replaced by a notch. An index fixed to the beton cylinder, at each revolution of the latter, pressed on one of the teeth, and advanced the disc one turn; after 20 revolutions, if the disc was properly placed at the start, the index turned free in the notch replacing the tooth which had been suppressed ; this indicated that the required number of turns had been accomplished. The blocking wedges were withdrawn from the wheels, the belt was loosened, and the beton cylinder ceased revolving. A mixing of beton lasted 5 minutes.

The travelling frame carrying the cylinder was run on to rails placed upon the platform of a truck, which transported it by a rail track to the head of the line of blocks in fabrication. The rails on the platform of the truck were on the same level as the rails on the floor of the mixing cylinders, and as the rails of the movable rail track set upon the blocks.

The frame carrying the beton cylinder was run upon the movable track, until it was stopped over the box mould which was to be filled. The cover of the beton cylinder was then opened, the latter turned half round on its axis, and the beton emptied into the mould below. The cylinder was then righted, and with open cover returned to the floor for another mixing.

The beton emptied into the mould was sufficient to cover the surface to a depth of $5\frac{1}{2}$ inches. This layer was equalized and firmly packed by three workmen provided with shovels, and rammers of 31 lbs. weight.

As each beton cylinder contained $\frac{1}{2}$ cubic metre of beton, it required 21 loads to fill a mould, taking into account the settling and compacting of the beton, which was 5 per cent. The fabrication of a block generally occupied an hour.

The pannels of the box-moulds rested on close-jointed wooden flooring which formed the bottom of the moulds. Across the bottom, and at about 0.50 metre from the ends, small hollow boxes of slats were placed, to form grooves in the block for the suspension chains used in handling. The lower grooves were continued vertically up the sides of the blocks. These side grooves were obtained by timbers of trapezoidal section, slightly fastened to the pannels of the moulds, and separated from the beton when the moulds were taken apart.

In the fabrication of the blocks, no voids were allowed in the interior, and the surfaces were required to be perfectly smooth, and to present the appearance of a coat of mortar.

The first of these conditions was fulfilled by ramming. The second was obtained by throwing the beton violently against the interior sides of the pannels ; the mortar alone adhered to the latter, the pebbles, etc., being thrown back. The surfaces of the finished block presented no sign of broken stone or pebbles. The upper surface of the block was smoothed with the shovel when the mould was completely filled.

In consequence of the ramming and of the weight of the beton before the setting took place, it sometimes happened that the pannels of the moulds were forced out of shape, and the blocks also. These deformations arose from the swelling of the vertical pannels, and the swelling prevented subsequently the blocks from being placed close together in building the courses of quay walls. This disadvantage was partly obviated by tightening bolts applied to the top and bottom of the moulds, and by bracing the pannels from the outside, when a neighboring line of blocks allowed it to be done.

The object of the vertical grooves left in the blocks during their fabrication was, to permit the suspension chains to lodge in them ;

without this precaution, the thickness of the chains would, of necessity, have obliged the blocks to be left considerably apart in building them into the courses of a quay wall.

The moulds were taken to pieces three days after completion of the filling; at this age the beton had acquired sufficient consistency to hold together, and to bear the weight of the movable rail track set on top, and used for running the beton cylinders back and forth. The blocks thus exposed to the air, remained in the yard during the time required for their complete drying and hardening. The length of time required varied from 40 to 50 days, according to the season. Sometimes blocks have been lifted and transported to the point of use in 29 days after fabrication.

The putting together and taking apart of the box moulds was easily accomplished. The moulds consisted of two side and two end pannels, joined together simply by juxtaposition, and kept in place by iron bolts, on one end of which a screw thread was cut, and a nut with a handle used for tightening. The taking apart consisted in loosening the nuts, and removing the separate pannels.

Lifting, Loading, and Transportation of the Blocks.—The lines of blocks in the yard ran parallel to each other, and were separated by a clear space of about 2 feet. The thickness of the sides of the moulds rendered this space necessary in any case, and it was also required for the movable rail track used in the transportation of the blocks.

The lifting and transporting of the blocks was effected by a *steam travelling crane.* (Frontispiece.)

The crane consisted of a strong sheet iron frame, 19½ ft. long by 9 ft. 2 in. wide, with 4 cast-iron wheels. The frame was divided by a sheet-iron partition into two compartments, the rear one with sheet-iron sides was empty and received the block; the fore compartment was covered with a floor upon which rested the steam engine, boiler and machinery. The engine was of 8 horse-power, vertical, non-condensing, with 2 cylinders and a tubular boiler.

A system of gearing transmitted the power, either to a vertical shaft which, by a cog-wheel on one of the axles, worked the travelling crane backward and forward, or else to a horizontal shaft which communicated the motion to two vertical screws used in lifting the blocks.

The travelling crane with its frame was carried by a truck with rails fixed on its platform. The truck travelled back and forth on the rail track G. (Plate II.) and placed the crane at the head of the different lines of blocks. The rails on the platform of the truck were on a level with the rails of the movable track established on the ground on each side of the blocks for the use of the travelling crane. The movable track consisted of heavy longitudinal oak ties carrying the rails.

When a line of blocks was ready for immersion, the travelling crane left the truck, and, passing across the sunken track F on to the movable track, approached the first block. The suspension chains, previously passed around the block and lodged in the grooves of the latter, were fastened to the ends of two horizontal beams, fixed to the lower part of the vertical screws. The beams consisted of two plates of sheet iron, strengthened and connected by iron braces; at their extremities a hole was cut for the key which held the end of the chain, and the beams, like the arms of a pair of scales, worked on a pivot at the point of fastening to the vertical screws, in order to be more easily attached to the chains.

The chains being attached, the horizontal shaft, extending the whole length of the upper part of the frame of the crane, was set in motion; on this shaft were two sections of an endless screw, which engaged with two horizontal pinions bearing teeth on their outer circumference, and through the centres of which passed the upright ends of the hoisting screws. The pinions formed the nuts of the screws, and as the former were prevented from rising, the latter were forced to ascend, carrying the block up with them. The travelling crane then transported the block over the sunken track F, and deposited it upon a truck below. To free the block, which was still surrounded by the sides of the crane, the latter moved on to the travelling frame or truck, on the outer track G, drawing after it by a hook and chain, the two girders forming a bridge across the sunken track, and which would have interfered with the passage of the truck loaded with the block. When the latter had moved away, the bridge girders were replaced, and the travelling crane returned across them to obtain another block.

The block was transported along the lower rail track, under a scaffold or derrick established on the shore; on the upper girders of the derrick a travelling windlass lifted the block and deposited it on a lighter. The loaded truck with the block was either drawn by an endless chain from a stationary steam-engine beneath the derrick, or else by a small locomotive, and later by horses.

The lighters were towed to the point of use by a steamer. They were generally made of the hulks of old sailing vessels, of which the deck was lowered. Three blocks were loaded on each lighter.

Employment of Artificial Blocks.—The blocks were used in protecting the seaward slope of the jetties, and also in the construction of quay walls. (Plate I.)

Jetties.—In the revetment of the jetties the blocks were used below and above the level of the sea, and the operation of placing them was different in each case.

Blocks Used Beneath the Level of the Sea.—The lighters used in transporting blocks to be sunk in the sea were prepared as follows: On the deck was established an incline capable of receiving 3 blocks, and on the timbers forming the ways, strongly greased pine skids were placed; a horizontal iron rod lay on the deck along the foot of the skids, and was kept in place at each end by two rings, through which it passed. To the rod were fixed 6 iron arms, two by two, so that two arms were in front of each block on the ways. At each end of the iron rod was a handle in the same plane with the iron arms, with which the rod could be turned in the rings. Before loading the lighter the handles were lifted upright, and kept in that position by a catch attached to the deck; the iron arms also were then vertical.

The blocks were lowered upon the ways, and kept in position by the iron arms against which they rested. When the lighter had reached the point of immersion, the catch holding the handles was let go, and the iron arms, being no longer retained in position, were forced over on to the deck by the weight of the blocks, which then slid off the lighter into the sea.

Blocks used above the Level of the Sea.—The blocks were deposited on a lighter, the deck of which was level, and towed to the point of use, where a floating derrick or sheers on a barge awaited them. The summit of the sheers reached 5.00 metres ($16\frac{1}{2}$ ft.) beyond the bow of the barge. A windlass, with a 10-horse power engine, worked a heavy iron chain over a pulley at the end of the sheers. The chain ended in four smaller chains, capable of being fastened together two by two.

The sheers and lighter being in proximity, the chains were passed around in the grooves of a block, the windlass set in motion, and the blocks suspended in air. By hawsers from the jetty, the barge and sheers were hauled in front of the point to be covered, and the block was lowered upon the slope of the jetty. The main chain was slackened, the small chains unfastened from the block, and the operation completed.

The placing of a block by this method occupied about 20 minutes, and in calm weather up to 31 blocks could be placed in a day, and generally 25 blocks. High tide was preferred for immersion, as the chances of breakage of the blocks were diminished by the greater thickness of water they had to pass through.

Quay Walls.—The general foundation of the jetty, etc., consisted of a bank of broken stones of various sizes, à pierre perdue, rising from the bed of the sea, at a depth of 17 metres (56 ft.). On the interior slope of the jetty, the bank was carried up at 45° to within about 6 metres ($19\frac{1}{2}$ ft.) of the level of the sea. At this depth it formed a wide bench or set-back, upon which the quay wall, composed of four courses of beton blocks, each 1.50 metres (5 ft.) high, was built up to the level of the sea.

The surface of the bench was too irregular to serve as a bed for the blocks, and it was levelled by filling up the inequalities and spaces between the large stones, with small gravel and broken stones.

For this purpose, a raft of wood was anchored over the site of the quay. In the floor of the raft, a rectangular aperture was made, with its longest sides in the direction of the width of the set-back. On one of the longer sides a plank apron was erected, inclined towards the opening. On the opposite side was a vertical apron of boards.

A lighter loaded with small broken stones and gravel was moored to the raft, and the materials were emptied in small quantities upon the inclined apron, and through the opening in the floor of the raft, into the sea. A workman standing behind the vertical apron to protect himself from the splashing of the water, directed with a sounding lead the levelling of the bed of the quay. The rough bed was equalized over a width of 8 metres (26 ft.), corresponding to the length of a block 3.40 metres (11.16 ft.), with an additional width of 2.50 metres (8 ft.) in front. (Plate I.) The diving-bell was used for removing any pieces of rock, which from their large size interfered with the regularity of the bed.

These preparations being completed, the blocks were loaded on lighters, towed to the site, and suspended in air by the floating sheers, in the same way as when used for the seaward revetment. To lower the block to its bed, 6 metres below the surface of the water, and to align it in the quay wall, an iron frame was used, consisting of 3 sides, each 2.00 metres ($6\frac{1}{2}$ ft.) long, and equal to the width of the block.

At each angle of the iron frame sockets were placed, in which were clamped upright wooden posts 6 metres high. When the block was ready to be lowered the frame was placed upon it, the two uprights being in the same plane with that side of the block destined to form part of the face of the wall.

When the block was submerged and directed into its proper place by the frame and uprights, its position below was indicated by the visible portion of the latter above water; it was thus sufficient to place the uprights in the alignment of the proposed quay wall, to be certain that the blocks were also in it. When a block was placed the suspension chains were withdrawn, as well as the iron frame, which was kept in position only by its weight.

The placing of the first course of blocks was the most difficult to accomplish, on account of the occasional unevenness of the bottom, caused either by the action of the waves, or by imperfect levelling; divers were then employed to remove the obstacles.

The joints of the blocks of each course were laid as close as possible, and the joints of two successive courses were crossed at half the width of the block. To complete a course, blocks were cut to the required dimensions for filling the vacant space.

The wall of beton blocks was continued above water by masonry which formed the quay wall proper. To avoid the disruption of the latter by any settling of the blocks from the additional weight, they were previously loaded during several months with two courses of blocks. The settling produced by this weight was frequently very irregular, and the consequent inequalities in the surface of the upper course of blocks were carefully levelled with layers of cement concrete at the level of low tide, from which point the quay wall of masonry was built up. The bench of 2.50 metres in width, at the base of the wall of artificial blocks, was generally destroyed, in part by the united effects of the weight of the wall and the action of the waves; it was re-established with broken stones and rocks placed by the workmen in the diving-bells.

Personnel and Labor required.

1º. Fabrication.

Steam Engine.	Engineer and fireman.........	2	men.
Pebbles.	Loading cars..............................	12	"
	Washing..................................	7	"
Sand.	Loading cars..............................	6	"
	Conducting cars to elevator...........	2	"
	Unloading and heaping sand.........	3	"
Lime.	Loading cars and conducting to elevator..................................	2	"
Floor of Mortar Mills.	Lifting cars..........	1	"
	Receiving lime and sand cars, and mill work..............................	6	"

Emptying mortar and pebble cars into beton cylinders.................. 5 men.
Lowering empty cars.................. 2 "

Floor of Beton Cylinders. Fabrication........ 2 "

Loaded and Empty Cars under Mortar Mill Floor.

Receiving mortar from mills.......... 2 "
Conducting mortar and pebble cars to elevator............................. 5 "
Receiving empty cars lowered from mill floor.............................. 2 "

Transportation of Beton, Ramming, Moulds.

Transportation of beton................ 9 "
Ramming beton (3 men per mould) 9 "
Putting up and taking moulds apart. 8 "

(3 Beton Cylinders in Transportation. 3 Beton Blocks in Fabrication.)

2º. **Lifting Blocks and Shipping.**

Steam Crane. Engineer and fireman........... 2 "

Lifting and Shipping. Placing movable tracks, and service of blocks...10 "
Transporting blocks to shipping derrick (2 H. P. locomotive)........... 2 "
Lifting block at derrick, and loading on lighter............................. 6 "

3º. **Transportation to Point of Immersion.**

Tow-boat. Officers and crew..................... 8 "

4º. **Employment of Blocks under Water.**

Number of lighters (1 loading, 1 transporting)......................... 2 lighters.
Labor in immersing..................... 8 men.

5º. **Employment of Blocks for Crowning Jetties or Quay Wall Foundations.**

Number of lighters for transporting 2 lighters.
Floating sheers.......................... 1 sheers.

Labor on sheers........................ 7 men.
Crews of lighters, and labor in immersing.................................. 6 "

Average Daily Production and Work.

Fabrication..............................12 blocks.
Employment of blocks under water..20 "
Employment of blocks, crown of jetties.................................16 "
Employment of blocks, quay wall foundations................................12 "

Description of a Smaller Yard of Fabrication.—The establishment of the plant described above entails a great expenditure, which can only be entered upon when a large quantity of beton is required. A smaller plant was established for the fabrication of 25,000 cubic metres (33,000 cubic yards) of beton to be immersed green for the graving docks of the port of Marseilles.

The plant consisted of a mortar mill for the fabrication of mortar, and a platform of planks on which the mixing of the mortar with the broken stones for beton was carried on. The wheels of the mortar mill were set in motion by a locomobile, which also worked a water-wheel for washing the pebbles.

The pebbles were deposited upon the platform in a long narrow heap of triangular section, and upon them was laid the proper quantity of mortar. The mixing was done by hand; three men with hoes on one side of the heap spread out the ingredients towards them on the board flooring, and were assisted by three men with shovels upon the opposite side. Two of the latter assisted in spreading out the mixture, whilst the third shovelled it over into a heap. The process of turning over was continued three times, and the beton was then sufficiently mixed. The beton in its passage across the platform, from its first to its third position, traversed during the mixing a distance of 6 metres, or about 6½ feet for each turning over.

The mortar on account of the peculiar character of the works in which it was to be used, was made with 400 kilog. of lime of Teil to 1.07 cubic metre of uncompacted sand (630 lbs. lime per cubic yard of sand). The beton consisted of three parts of pebbles to two parts of mortar.

The pebbles were transported to the platform in wheel-barrows, of which the volume was 2.37 cubic feet. The bottom of the barrows consisted of open work, to let the water run completely off, after washing the pebbles in the barrows.

The mortar was transported on barrows with a raised edge upon three sides, so as to give a volume of 1.59 cubic feet. The cubic contents of the pebble and mortar barrows were thus in the proportion of 3 to 2, and to avoid confusion, a barrow full of pebbles deposited on the mixing area was always followed by a barrow full of mortar, before the arrival of the next barrow of pebbles.

The beton made as above, was shovelled into sheet iron semi-cylindrical boxes for immersion. The boxes were placed on boats and transported to the point of use, where they were lifted by a crane set upon the caissons, and lowered into the water to form the hearting of the sea wall.

The daily fabrication was 60 cubic metres of beton.

The labor required for this production was :

	Steam Engine	1 man.
	Transportation of sand	4 men.
	do. of lime and work at mill	4 "
Pebbles.	Loading barrows and washing	10 "
	Returning barrows to platform	1 man.
	Loading mortar barrows, and emptying mortar on pebbles	8 men.
	Mixing beton (two gangs of men)	12 "
	Loading beton into boxes	5 "
	Transporting boxes by boat (3 boats and 3 boxes per boat)	9 "
Immersion.	Windlass	4 "
	Emptying boxes	2 "

Cost of Fabrication of Teil Beton Blocks.—In the important works of the construction of the Napoleon Basin and Jetty at Marseilles in 1857, of which M. Pascal was Chief Engineer, and MM. Dussaud Bros. Contractors, 10,000 artificial blocks of Teil beton were employed; the volume of each block was 10 cubic metres, 353 cubic feet.

The cost of fabrication, although lower than what it would be to-day, is interesting as giving the relative cost of the different items, and the proportions of beton.

Teil Beton for Artificial Blocks. (Marseilles.)

286½ lbs. of Teil lime at 28 fr. per ton	$0 73
Weighing, transporting and storage of lime	0 08
0.45 cubic yard of sand at 3.82 fr. per cub. yd.	0 35
1 cub. yd. of pebbles at 2.68 fr. per cub. yd.	0 53
Fabrication, inclusive of taking moulds apart, cost of moulds, &c., and groove boxes	0 46
Lifting, transporting, immersing, inclusive of cost of plant	0 46
General expenses $\frac{1}{20}$	0 09
Profit of contractor $\frac{1}{10}$	0 19
Cost* per cubic yard of artificial block in final position	$2 89

Teil Beton for immediate immersion. (Marseilles.)

337 lbs. of Teil lime at 30 fr. per ton	$0 92
0.54 cub. yd. of sand at 3.44 fr. per cub. yd.	0 37
0.90 cub. yd. of broken stone at 2.68 fr. per cub. yard	0 48
Fabrication and immersion	0 61
General expenses $\frac{1}{20}$	0 12
Profit of contractor $\frac{1}{10}$	0 25
Cost per cubic yard of beton immersed green	$2 75

Since the execution of these important works, the cost of Teil hydraulic lime has considerably increased, owing to its demand for works such as those of the Suez Canal, Alexandria Harbor, etc.

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* All prices and costs given in gold.

In the construction of the Port Said Breakwaters, in 1865 to 1868, the cost of Teil beton per cubic yard of artificial block was $6.40 ; the cost of the block in final position was $15.30 per cubic yard.

The cost of fabrication by machinery of Teil beton for artificial blocks, at any point near New York, may be estimated as follows, adopting the proportions actually employed by French engineers of 590 lbs. Teil hydraulic lime per cubic yard of sand, producing 1.10 cubic yards of mortar, and one volume of Teil mortar to two volumes of broken stone. Teil hydraulic lime costs $21.75 per ton, delivered in dock, New York ; the cost of sand, broken stone, and labor is based upon the results obtained by General Gillmore in 1870 to 1871, in making concrete for the Staten Island Forts :

Teil Beton for Artificial Blocks. (*New York.*)

266 lbs. Teil lime, at $21.75 per ton of 2,240 lbs....	$2 58
1.45 cub. yds. of sand, at 36c. per cubic yard.......	0 16
0.50 cubic yard Teil mortar.	
1 " " of broken stones and pebbles. at $2.00 per cubic yard	2 00
Fabrication of beton (mixing, transporting to moulds, ramming), inclusive of taking moulds apart, cost of moulds, etc., and groove boxes......	1 60
Cost of Teil beton per cubic yard of block............	$6 34
Lifting, transporting, immersing, inclusive of cost of plant	2 00
General expenses $\frac{1}{20}$..	0 42
Profit of contractor..	0 88
Total cost per cubic yard of artificial block in final position..	$9 64

In betons made with Portland cement, it is a common practice to cheapen the product by employing equal volumes of cement and slaked ground non-hydraulic lime in powder, instead of cement alone.

With Portland cement alone, weighing 106 lbs. to the bushel, it is expensive to fulfil the conditions of a good mortar by filling the voids in the sand, and the use of the common lime is to remedy the lack of volume of the cement at the expense of homogeneity, and of a better resistance to the action of sea-water.

The opinion is gaining ground among many engineers, that it is preferable to employ a single lime or cement at a time in a mortar or beton instead of various mixtures, and that a good hydraulic lime used by itself is better than a mixture of a good cement and an ordinary lime, or of an ordinary lime and pozzuolana.

Teil lime weighing 56 lbs. to the bushel, gives not far from double the volume of the same weight of Portland cement. It is strongly hydraulic, very uniform in composition, and as its quality is invariable, Teil lime produces very homogeneous mortars and betons, which resist the action of sea-water.

For artificial blocks for marine structures, a beton of first rate quality can be made as above mentioned, for $6.34 per cubic yard of finished block. The same beton, in which the Teil lime, weighing 266 lbs., has been replaced by an equal volume of Portland cement, weighing 504 lbs. (at $20.60 per gross ton), would cost, the other items remaining the same, $8.39 per cubic yard of finished block, showing an increased cost of about 30 per cent.

If one-half of the volume of Portland cement is replaced by a common lime (252 lbs. of cement, at $20.60, and 178 lbs. of lime at $5 per gross ton), the other items remaining the same, the economy obtained by the use of Teil beton is about $0.14 per cubic yard, the prices of both betons being respectively $6.48 and $6.34 per cubic yard of block. In this case the chief advantage attending the use of Teil hydraulic lime, is that a more reliable and homogeneous beton is obtained, which can be depended upon to resist the action of the sea.

CERTIFICATES.

Port of Marseilles. (Mediterranean Sea.)

1. Teil lime, from the quarries of Messrs. L. and E. Pavin de Lafarge, has been employed for upwards of 16 years in the department of Bouches-du-Rhone. It has been used almost exclusively in the construction of La Jolliette and of the Frioul, notably in the fabrication of artificial blocks for the exterior slope of the jetties where they would receive the shock of the waves, and in the masses of concrete for the foundations of quay walls. The concrete in the artificial blocks was immersed after a preliminary drying in air for several months; the masses of concrete for foundations were immersed green.

All the works made with this lime have resisted perfectly the chemical action of salt water, and the shock of the waves. Of the great number of mortars made of various hydraulic limes on which we have experimented to determine the tensile strength, those made of Teil lime occupy the first place. Teil mortars have been used both in fresh and salt water, in masonry and as a coating. In these uses we have also found them far superior to other hydraulic mortars.

The Engineer-in-Ordinary,
(Signed) Pascal.

Marseilles, 17*th Feb.*, 1855.

2. To-day, on the termination of the works of the Napoleon Basin and of those of the Marseilles Docks and Warehouses Basins, exclusively constructed with the hydraulic limes of Teil (Ardèche) derived chiefly from the quarrries of MM. Pavin de Lafarge, we can testify to the superiority of these limes.

The Engineer-in Chief,
(Signed) Pascal.

Marseilles, 13 *Feb.*, 1867.

3. The undersigned, Engineer-in-Chief of Bridges and Highways, charged with the direction of the works of the Port of Marseilles, certifies that since 1840 the hydraulic limes of Teil have been exclusively employed in these works, of which the value is about fifty millions, and that they have given the best results.

It was on account of these ascertained facts that in nearly all the great works of the Mediterranean Ports recourse was had to these limes.

We would mention Algiers, Port Said on the Suez Canal, and the Port of Trieste.

(Signed) PASCAL.

MARSEILLES, 25*th Nov.*, 1872.

4. I, the undersigned, Engineer in Ordinary of Bridges and Highways, in charge of the Works of the Second Maritime Division of the Bouches-du-Rhone, certify that the firm of Mathieu Couturier (now Soullier & Brunot), lessee of the Hydraulic Lime Quarry of "Detroit," situated in the Commune of Teil (Ardèche) and belonging to that Commune, has been allowed since the year 1858, simultaneously with MM. Pavin de Lafargé, to furnish the Teil hydraulic limes required for the Maritime Works of the Bouches du Rhone and that it has since that date received the adjudication of seven contracts for the Second Division as follows :

Dec. 22, 1859.	Construction of Draw-Bridge at Martigues	1,400 Tons.
Sep. 29, 1864.	Construction Graving Docks, Port of Marseilles	6,500 "
Aug. 14, 1866.	Completion of Sewers of Plombieres and Aygalades, Pt. of Marseilles	180 "
Oct. 24, 1868.	Construction Graving Docks, Port of Marseilles	2,200 "
Jan. 18, 1869.	Construction Graving Docks, Port of Marseilles	882½ "
Aug. 9, 1870.	Construction Graving Docks, Port of Marseilles	1,550 "
Aug 9, 1870.	Construction Second Draw Bridge on the Joliette Traverse	200 "
		12,912½ Tons.

I certify, moreover, that the firm Mathieu Couturier always fulfilled to the satisfaction of the Administration the obligations incurred by its contracts.

(Signed) DENANIEL.

MARSEILLES, *July* 23, 1872.

Countersigned by the Chief Engineer of the Maritime Works,

(Signed) PASCAL.

MARSEILLES, *July* 27*th*, 1872.

5. I, the undersigned, Ingénieur Ordinaire des Ponts et Chaussées, in charge of the Works of the First Maritime Division of the Bouches-du-Rhone, certify that the Association formerly known under the firm name of Couturier, Soullier & Co., and at present as Soullier & Brunot, which Association is lessee of the Hydraulic Lime Quarry of "Detroit," situated on the Commune of Teil (Ardèche), and belonging to that Commune (the said Association being represented successively before the Administration by M. Couturier and M. Soullier), has been allowed since the year 1858, simultaneously with Messrs. Pavin de Lafarge, to furnish the Teil Hydraulic Limes required for the Maritime Works of the Bouches-du-Rhone, and that the said Association has, since the said date, furnished a series of the said limes, destined for the works of the above-named First Division, of which the dates, objects, and quantities are enumerated as follows:

Adjudication, 15th July, 1858. Completion of the Belt Sewer of the Port of Marseilles....................................	1200 Tons.
Adjudication, 13th Sept., 1859. Improvement of the Quays of the Joliette Basin, Marseilles.............	350 "
Adjudication, 9th July, 1861. Construction of the Quay Walls, Napoleon Basin, Marseilles...........	2450 "
Adjudication, 17th June, 1862. Fabrication of Artificial Blocks. Completion of Napoleon Basin Jetty..	4500 "
Adjudication, 12th May, 1864. Fabrication of Artificial Blocks for Jetties of Imperial Basin..........	9700 "

From 1868 to 1871 various works at Port Ciotat (recharging the seaward slope of the prolongation of the New Mole with artificial blocks. Underpinning repairs of quay wall of Old Mole, and of quay wall of the prolongation of New Mole. Reconstruction of part of quay wall of Old Mole; construction of a shelter for fishing boats in the Meadow Cove)..	210 Tons.
Adjudication of October 25, 1871 (approved by Ministerial decision the following 27th December), recharging the seaward slope of the prolongation of the New Mole with artificial blocks...............	175 "
	18,585 Tons.

I certify, moreover, that MM. Couturier & Soullier have always fulfilled, to the satisfaction of the Administration, the obligations they had incurred towards it by undertaking to supply the above materials.

(Signed) André.

Marseilles, 24 *July*, 1872.

Countersigned by the Chief Engineer of the Maritime Works,

(Signed) Pascal.

Marseilles, *July*, 1872.

Port Said. Suez Canal.

Compagnie Universelle
du
Canal Maritime de Suez.

I, the undersigned, certify that the artificial blocks with which the great Jetties of Port Said were constructed, from 1865 to 1868, by MM. Dussaud Bros., Contractors, under the superintendence and inspection of the engineers of the Company, were made with the hydraulic lime of Teil of MM. L. & E. Pavin de Lafarge, and that with regard to quality, homogeneity, hardness, etc., etc., this lime has always given excellent results.

I certify, moreover, that during the three years of the construction of these works, the establishment of Lafarge furnished for them alone upwards of eighty thousand tons of lime.

For the President,

(Signed) CH. A. DE LESSEPS.

PARIS, 11th *January*, 1873.

Port of Toulon. (MEDITERRANEAN SEA.)

1. I certify that since more than 20 years that Teil hydraulic lime has been used in the works of the port of Tonlon, this lime has always given excellent results in sea-water as well as in fresh water or exposed to the air, and for coating masonry; that no alterations have ever been observed in the mortars made with this lime and used in sea-water; that in the works executed by the Navy at Port Vendres, blocks of masonry with Teil lime have been constructed, and that these blocks employed in the revetment of the mole have resisted perfectly both the shock of the waves and the chemical action of salt water.

The Engineer-in Chief of the Ponts et Chaussées, Director of the Hydraulic Works of the Navy,

(Signed) NOEL.

TOULON, 10*th Feb.*, 1855.

2. The Engineer-in-Chief of the Ponts et Chaussées, Director of the Hydraulic Works of the Navy, certifies that, during the last 12 years, the hydraulic lime of Teil of MM. Pavin de Lafarge has been almost exclusively employed at the Port of Toulon for all marine structures, and particularly in the fabrication of 153,000 cubic metres of concrete for the three graving docks of Castigneau, and that it has always given good results and a notable economy over the use of pozzuolana.

The lime of Teil is also usually employed for the coating and the cornices of masonry, and behaves very well exposed to air. The result of a visit, which he has made recently, shows that the blocks of the Port Vendres Jetty, made of Teil mortar, have resisted the action of the sea perfectly, and that no perceptible alteration has been noticed in the works executed with Teil lime during the last 25 years at Toulon.

(Signed) RAOUL.

TOULON, 3*d* *Jan.*, 1867.

Port of Cette. (MEDITERRANEAN SEA.)

1. The undersigned, Engineer-in-Ordinary of the Ponts et Chaussées, certifies that the lime of Teil (Ardèche) is the only lime employed for the maritime works of the Port of Cette since 1852; the works constructed since that date show great hardness, and not the slightest trace of decomposition.

(Signed) SALVA.

CETTE, 12*th* *Jan.*, 1867.

2. The undersigned, Engineer of the Ponts et Chaussées, certifies that the lime of Teil derived from the establishment of MM. Couturier, Soullier & Co., has been employed in 1864 and 1865 for the fabrication of artificial blocks of beton, and for the submerged concrete of the foundations of the quays which were reconstructed in the Canal of Cette, and that it has given good results.

(Signed) SALVA.

CETTE, 6*th* *April*, 1867.

Port Vendres. (MEDITERRANEAN SEA.)

I, the undersigned, Alfred Pasqueau, Engineer of the Ponts et Chaussées, attached to the ordinary service of the Department of Pyrénées Orientales, and to the special service of the Port and Railroad of Port Vendres, certify that the artificial blocks of masonry made since 1844 with Teil-Lafarge hydraulic lime, for the construction and preservation of the mole of Port Vendres, are in a state of perfect preservation, and do not show any trace of disintegration. I certify, moreover, that the same lime has been almost exclusively employed in our service for the construction of masonry works of the Port Vendres Railroad, and of the Imperial Roads, and that it has always given excellent results, with regard to quickness in setting as well as to strength of the mortars made.

In belief of which I have written this certificate, to give value where it is due.

The Engineer in Ordinary,

(Signed) PASQUEAU.

PERPIGNAN, 10*th January*, 1867.

Port of Saint Malo. (BRITISH CHANNEL.)

The undersigned, Engineer-in-Chief, certifies that the mortars made of Teil lime and sea sand, used in the blocks of masonry, and immersed in the sea during 8 years at Saint Malo, are to-day very hard and in perfect preservation.

In belief of which this certificate has been delivered to M. de Lustrac.

The Engineer-in-Chief,

(Signed) BELLINGER.

SAINT MALO, 30*th August*, 1862.

Pointe-de-Grave. (BAY OF BISCAY, ATLANTIC OCEAN.)

The undersigned, Engineer in Ordinary, in charge of the defensive works of the Pointe-de-Grave, Department of the Girande, certifies as follows:

He had constructed during the month of March, 1860, five blocks, each 9 cubic metres in volume; three were made of ordinary masonry and two of beton, composed of three volumes of mortar to five of pebbles. The mortar used contained 4 kilogrammes of Teil lime furnished by M. Pavin de Lafarge, to 10 litres of sand.

These blocks were immersed on the Eastern slope of the Pointe-de-Grave jetty, at the end of the month of May, 1860; a scouring of the bed of the sea, which occurred on the 13th November, 1864, having caused them to disappear in the sea, where they were covered by other blocks, it is no longer possible to verify the state of preservation in which they are at present.

Previous to the 13th November, 1864, these five blocks, which had been on several occasions minutely examined, did not show any trace of decomposition.

In belief of which the undersigned delivers this certificate to M. Pavin de Lafarge, for him to use as he shall see fit.

(Signed) ROBAGLIA.

BORDEAUX, 22*d January*, 1867.

Port of Saint-Jean-de-Luz. (BAY OF BISCAY, ATLANTIC OCEAN.)

I, the undersigned, Engineer-in-Chief of the Ponts et Chaussées, in charge of the service of the maritime works of the Basses-Pyrénées and the Landes, certify that the mortar brick delivered to M. de Lustrac, agent of MM. Pavin de Lafarge, manufacturers of Teil lime, to be sent to the exhibition, was made on the 15th April, 1865, of a mixture of three parts in volume of sand to one part of Teil lime, derived from the establishment of MM. Pavin de Lafarge, and mixed with fresh water; that it was deposited on the 12th May, 1865, in the experimental bath of the Tour des Signaux, at the mouth of the Adour river, filled with sea-water renewed every eight days, and that it remained constantly immersed until this day.

I certify, moreover, that since 1865, Teil lime has been employed in the fabrication of small artificial blocks for the Sacoa breakwater, at the entrance of the bay of Saint-Jean-de-Luz, the actual state of which blocks cannot be ascertained, as they were used in the foundations and mixed with natural blocks and large artificial blocks of Portland cement mortar.

The Engineer-in-Chief of Maritime Works,

(Signed) DAGUENET.

BAYONNE, 2*d January*, 1867.

Port of Barcelona (MEDITERRANEAN SEA.)

1. D. José Rafo, Inspector generale de segunda clase del Cuerpo de Ingenieros de Caminos, Canales y Puertos, Caballero de la Real y distinguida orden de Carlos Tercero, etc.

Certifico: Que como director que he sido de la obras del Puerto de Barcelona, he empleado para la confeccion de los sillares artificiales de hormigon hidraulico de muelle de la muralla de mar, la cal hidraulica de Teil del establecimiento de MM. L. et E. Pavin de Lafarge cuyo material ha correspondido perfectamente al objeto a que se destino, dando resultados sumamente satisfactorios.

Y para que conste asi donde convenga, espido este documento a peticion del interesado, en Barcelona a quince de noviembre de mil ochocientos sesenta y seis.

(Signed) José Rafo.

Barcelone 15*th Nov.*, 1866.

2. Don Mauricio Garrau, Comendador de la Real distinguida orden de Isabel la Catolica, Ingeniero jefe del cuerpo de caminos, canales y puertos. Jefe de la provincia de Barcelona, etc.

Certifico: que se ha marcado con el sello de la oficina de obras publicas de esta provincia, una muestra de hormigon, cortada de uno de los bloques construidos por los SS. Delsol y Martin para las obras del puerto de Barcelona, que se hallan baso me direccion, y cuyo bloque fué construido el dia 6 de octubre de 1863 y sumergido en el mar en abril de 1864, en donde ha permanecido hasta el presente.

El hormigon, que le constituye, esta compuesto en volumenes iguales: de una parte de cal hidraulica de Teil y dos de arena de mar para formar la mezcla o mortero hidraulico; y tres partes de este con cinco de piedra machacada, para construir el hormigon.

Y para que conste, y a peticion de los SS. Delsol y Martin expido la presente en Barcelona a trece de marzo de mil ochocientos sesenta y siete.

(Signed) Mauricio Garrau.

Port of Algiers. (Mediterranean Sea).

The undersigned, Engineer-in-Chief of the Ponts et Chaussées, certifies that the lime of Teil, derived from the quarries of MM. Pavin de Lafarge, has been employed since 1852 in the hydraulic works of the Port of Algiers.

Mixed with sea-sand, it has been used in the fabrication of mortars for concrete immediately immersed, and for artificial blocks immersed after a previous drying in air of from two to two and a half months, according to the season, and the method of use by sea and by land. The mortars thus made have acquired very great hardness, and to-day they do not show any trace of alteration or decomposition by the shock of the waves or by the chemical action of sea-water.

The Engineer-in-Chief certifies, moreover, that Teil lime has been employed successfully in the works in the sea, and that it is very hydraulic, very active and quick, and very homogeneous.

J. DE SERRY.

ALGIERS, 7*th March*, 1867.

Port of Oran. (MEDITERRANEAN SEA.)

I, the undersigned, Engineer-in-Ordinary of the Ponts et Chaussées, in charge of the hydraulic works of the Port of Oran, certify, that the piece of concrete delivered to the firm Pavin de Lafarge du Teil (Ardèche), was taken in February, 1861, from an artificial block of 15 cubic metres, immersed in the jetties of the Port of Oran in 1853, after a sojourn of 13 years in the sea; that the concrete was composed of one part of mortar and two parts of broken stone, and the mortar was composed of 350 kilogrammes of Teil lime, derived from the establishment of Pavin de Lafarge, to one cubic metre of sand.

F. ROBIN.

ORAN, 8*th February*, 1867.

(Countersigned.)

The Engineer-in-Chief,

AUCOUR.

Port of Philippeville. (MEDITERRANEAN SEA.)

The undersigned, Engineer of the Ponts et Chaussées, certifies that the fragment of block attached to this certificate was made on the 22d March, 1862, and immersed on the 15th October, 1863, on the interior of the small enclosed basin of the Port of Philippeville.

The beton composing this sample is composed of two volumes of broken stone and one volume of mortar; the mortar itself contains per cubic metre of sand, 370 kilogrammes of Teil lime sold by the firm of Pavin de Lafarge; the lime is delivered at Philippeville, screened in powder, and enclosed in sacks.

Besides its well-known qualities, the lime of MM. Pavin de Lafarge is distinguished by an absolute homogeneity.

Certified by the Engineers in charge of the Works.

For the Engineer-in-Chief, De Lannoy, Absent,

The Engineer-in-Ordinary,

(Signed) Gay.

Constantine, 28*th Jan.*, 1867.

Port of Ajaccio. (Mediterranean Sea, Corsica.)

I, the undersigned, Ingénieur Ordinaire des Ponts et Chaussées, certify that the blocks of concrete numbered consecutively from 1 to 10, are derived from the end of the Margonojo jetty (Port of Ajaccio), executed in 1861 by myself, under the direction of M. Vogin, Chief-Engineer of the Department.

The concrete consisted of three parts of broken stone and two parts of hydraulic mortar; the mortar consisted of 8 parts of sand to 5 of hydraulic lime from the quarries of Teil (Ardèche), belonging to MM. Pavin de Lafarge.

The blocks in question formed part of the foundation of the jetty; they were taken from about 10 centimetres below the level of the sea.

I certify, moreover, to having employed Teil hydraulic lime (quarries of MM. de Lafarge) in various works in the sea, and I declare that the mortars and concretes manufactured with this lime have until now resisted perfectly and have given excellent results.

(Signed) Koziarowicz.

Ajaccio, 11*th Feb.*, 1867.

Port of Bastia. (Mediterranean Sea, Corsica.)

1. The block of concrete which is to figure in the Exhibition of 1867, and which bears a ticket giving the number of the present certificate, was obtained from one of the artificial blocks of the revetment of the ancient jetty of the Mole Génois.

This artificial block, of which the upper surface is 0.60 metre below the level of low tide, was made and submerged in 1852, at which time the works were directed at Ajaccio by M. Hernoux, Engineer-in-Chief, and at Bastia by M. Vogin, then Engineer-in-Ordinary of the Northeast Division, and at present Engineer-in-Chief of the Department. The concrete in question consisted of 2 parts of broken stone and one part of hydraulic mortar; the mortar was composed of 0.90 in volume of sand to 0.62 in volume of lime manufactured at Bastia with Teil limestone. A large number of concrete foundations and artificial blocks of concrete have been made at Bastia with Teil lime from the firm of Pavin de Lafarge. These concretes have until now resisted successfully the action of the sea; the sample to which the present certificate refers was chosen as belonging to one of the oldest blocks; the operations were under the supervision of M. Bonavia, Chief Conductor in the Ponts et Chaussées.

Certified as correct by the undersigned Ingénieur Ordinaire,

(Signed) DONIOL.

BASTIA, 10*th Jan.*, 1867.

2. I, the undersigned, Ingénieur Ordinaire of the Ponts et Chaussées resident at Bastia (Corsica), certify that the hydraulic lime from the Detroit quarries situated in the Commune of Teil (Ardèche) and worked by MM. Couturier, Soullier & Co., is designated in the specifications of the department for works in the sea simultaneously with the lime derived from the Teil quarries of MM. Pavin de Lafarge. I certify, moreover, that the lime of MM. Couturier, Soullier & Co., is employed actually for the South Quay of the Port of Bastia, where until now it has given good results.

(Signed) DONIOL.

BASTIA, 7*th March*, 1867.

Countersigned and approved by the undersigned Chief Engineer.

(Signed) VOGIN.

AJACCIO, 11*th March*, 1867.

Port of Isle-Rousse. (Mediterranean Sea, Corsica.)

The Mayor of the town of Isle-Rousse, Department of Corsica, certifies that the fragment of a block, sent to-day as a sample by M. Padorami of this town, to the firm of Pavin de Lafarge, at Marseilles, has been detached from a huge block immersed in the sea in 1852 during the construction of the works of this port, consisting of pebbles mixed with sand and hydraulic lime under the superintendence of M. Lacroix, Ingenieur-en-Chef des Ponts et Chaussées, and M. Lesguittier, Ingenieur-Ordinaire. In belief of which he has delivered the present certificate.

The Mayor,

Piccioni.

Isle-Rousse, 9*th Feb.*, 1867.

Port of La Spezzia. (Mediterranean Sea. Italy.)

1. *Genio Militare.*

Derezione di Spezia Marina.

Arsenale Militare Marittimo di Spezzia.

Il sotto scritto in seguito a richista delli Signori Pavin Lafarge, fabbricanti di calce idraulica del Teil (Ardèche) dichiara che nei diversi lavori idraulici di questo arsenale marittimo venne impiegata al giorno d'oggi una quantita di circa tonnellate 3,000 di detta calce del Teil e che y risultati ottenuti riescirono sempre pienamente soddisfacenti.

Tanto attesta il sotto scritto per la pura verita.

Il Maggiore Generale Direttore,

(Signed) Chiodo.

Spezia, *il* 7 *Febbrajo*, 1867.

2. *Servizio del Genio Militare.*

Arsenale Militare Marittimo di Spezzia.

Nei lavori di costruzione di questo arsenale militare Marittimo di Spezia si consumaiono nello spazio di un' anno 4,000 Tonnellate di calce idraulica del Teil (Ardèche) proveniente dalla fabrica dei Signori Pavin de Lafarge et Couturier, Soullier & Co., la quale deide ottimi risultati in ogni genere di costruzione sia quando venne impiegata nella formazione all' as ciutto dei muri dell Darsene in cui dopo pochi giorni venne introdotto l'acqua nel qual lavoro si pote osservare prima una repentina présa si detta calci fuori acqua e poscia una resistenza assoluta al constatto delle acqua, sia quando fu adoperata per la formazione di calcestruzzo versato nel mare e di massi artificiali eseguiti fuori acqua nei quali si verifico dopo poćo tempo un solido indurimento resistente a forti pressioni senza cedimento o sgranamento.

Perciò questa Direzione del Genio Militare si crede in obligo di manifestare a codesti Signori Provveditori la sua piena soddisfazione sulla buena qualità ed ottini risultati dati dalla sopradetta calce e sul perfetto confezionamento in cui essa arrivo finora in questo porto.

Il Maggiore Générale Direttore,
(Signed) CHIODO.

SPEZZIA, 2 *Aprile*, 1867.

City of Tunis. (MEDITERRANEAN SEA.)

Praises be to the One God.

The general of brigade, Mohammed, chief of the municipality of Tunis, who has affixed his seal to the foot of these presents, certifies at the request of MM. Pavin de Lafarge, manufacturers of hydraulic lime, to having had extracted from cisterns constructed in 1863, with the hydraulic lime of this manufacture, a block of *concrete*, which bears as a stamp the seal of the Consulate General of France at Tunis.

He declares, moreover, that the composition of this *concrete* is 350 kilogrammes of hydraulic lime to each cubic metre of sand. Written the 13th of Choual, 1283.

The Chief of the Municipality of Tunis,
(Signed) KAVA MOHAMMED.

17*th February*, 1867.

City of Odessa. (Black Sea, Russia.)

The Paving Committee of the City of Odessa has given this certificate to MM. Pavin de Lafarge, manufacturers of hydraulic lime in the village of Teil (France), and furnishers of this lime for the granite pavement of Odessa, to certify that the sample of pavement delivered to them was taken out on the 8th inst. from the pavement of the military causeway, put down in 1863. The model is one archine in length, and over one-half an archine in breadth ; it consists of ten stones each of seven inches, and is sealed at the four corners with the seal of the President of the Committee. The present certificate is certified to by the signature of the President of the Committee, the counter signature of the Secretary, and stamped with the same seal as the pavement model.

The President of the Committee, Actually Councillor of State,
(Signed) Andriesski.
The Secretary,
(Signed) Fialkovski [l. s].

Odessa, 23*d* *Feb.*, 1867.

Province of Constantine. (Algeria.)

We, the undersigned, Ingenieur en Chef des Ponts et Chaussées, of the Constantine Division, declare that we have employed the hydraulic lime of Teil, from the kilns of MM. Pavin de Lafarge for a great number of various kinds of works, in fresh water as well as in the sea, on the shores of the Mediterranean, and that we have observed in this lime all the qualities of an eminently hydraulic lime of the first order. Not only have the mortars made with this lime acquired in a short time a very great hardness, but they do not appear to be susceptible to decomposition by the sea-water of the Mediterranean. Employed in air, Teil mortars are susceptible of forming masonry of much greater strength than common masonry, and we have observed that in the bridge of El-Kantara during the trial loads made in 1864, the piers of this bridge, built of limestone and Teil lime, supported during 48 hours without damage a pressure of 18 kilogrammes per square centimetre.

We would add that during great heats, many limes are of difficult use, and the mortars made with them are subject to rapid alteration. Now we have observed that the masonry of the El-Kantara Bridge acquired in a short time very great solidity, although during the execution of the works the solar heat was frequently as high as 50 to 57° C.

(Signed) DE LANNOY.

CONSTANTINE, *27th April*, 1866.

Canal of Forez. (FRANCE, DEPT. OF THE LOIRE.)

The undersigned, Ingenieur Ordinaire des Ponts et Chaussées, certifies that MM. Couturier, Soullier & Co., manufacturers of lime of Teil (Ardèche), have furnished in 1866 two thousand and sixty-three tons (2,063 tons) of screened lime for the first division of the Forez Canal, and that from the experiments daily made in the workshops the Teil lime of the above named manufacturers is as eminently hydraulic as that of the Lafarge Works, which was used at the same time in the same works.

(Signed) FEUESTEIN.

ST. ETIENNE, *30th March*, 1867.

Mont Cenis Tunnel.

The undersigned, Engineer of Bridges and Highways, attached to the Construction of Railroads of the Paris-Lyons-Mediterranean Co., certifies having made frequent use of Teil hydraulic lime (Ardèche) in the works under his direction, and having always obtained excellent results, as well in works under water as in tunnels and other works.

In the St. Michel Section, especially in the Mont Cenis Tunnel (13 miles), this lime was used to the extent of upwards of 5,000 tons, notwithstanding the distance from the kilns, and the increase of cost due to transportation. It rendered services which were highly appreciated in all works which required exceptional hydraulic qualities.

The Engineer of the P. L. M. R. R. Co.,

(Signed) F. MORIS.

CHAMBÉRY, *9th Nov.*, 1872.

Railroads.

1. *Lyons & Mediterranean Railroad.*

I certify that I have frequently used since a long time the hydraulic lime of Teil in the works of all kinds which I have had executed in the south of France, and always with uniform success.

The activity of these limes, their homogeneity, and the uniformity of the results which they give, are admitted without question by all the engineers of the South.

The use of the methods of crushing and screening, first put in practice by M. de Villeneuve, add still more to its qualities, and contribute in placing to-day the lime of Teil at the head of all the hydraulic limes of France.

The Ingenieur-en-Chef des Ponts et Chaussées, Director of the Paris-Mediterranean R. R. Co.,

(Signed) PAULIN TALABOT.

PARIS, 12*th March*, 1855.

2. *Southern Railroad.*

The undersigned, Engineer of the Southern Railroad Co., certifies that the contractors of the Bridges of Pinsaguel, on the Garonne river, and of Saverdun, on the Ariegè river (St. Simon & Foix Railroad), as well as of the Castelnaudary Tunnel (Castelnaudary & Castres Railroad), have employed in the construction of a large portion of these works, the Teil hydraulic lime, derived from the establishment of MM. Couturier.

He certifies moreover that the use of this lime has given excellent results.

(Signed) GUILLAUME.

CASTRES, 28*th July*, 1864.

Countersigned.

The Chief Engineer of the Castres Division,

(Signed) A. ALBY.

CASTRES, 17*th Oct.*, 1864.

3. *Paris-Lyons-Mediterranean Railroad.*

The undersigned, Chief Engineer of the Paris-Lyons-Mediterranean R. R. Co., at Marseilles, certifies that since the 27th Feb., 1855, at which time he gave a certificate stating the good results obtained by him in the use of the hydraulic limes of the establishment of MM. L. and E. Pavin de Lafarge at Teil (Ardèche), he has constantly used the lime of MM. de Lafarge, in the works of the Paris-Lyons-Mediterranean R.R. Co., as well as in the constructions of the Marseilles Docks and Warehouse Co., for the parts of said works most subjected to humidity or strains, and that he has never ceased to obtain perfectly satisfactory results.

(Signed) J. Desplaces.

Marseilles, *7th March,* 1867.

PORT NAPOLEON

GREAT JETTY

MARSEILLES

PLATE F.

Scale of 0m·005 to a metre (1/200)

Quay Walls built with Artificial Blocks of Teil Concrete
Port of Marseilles

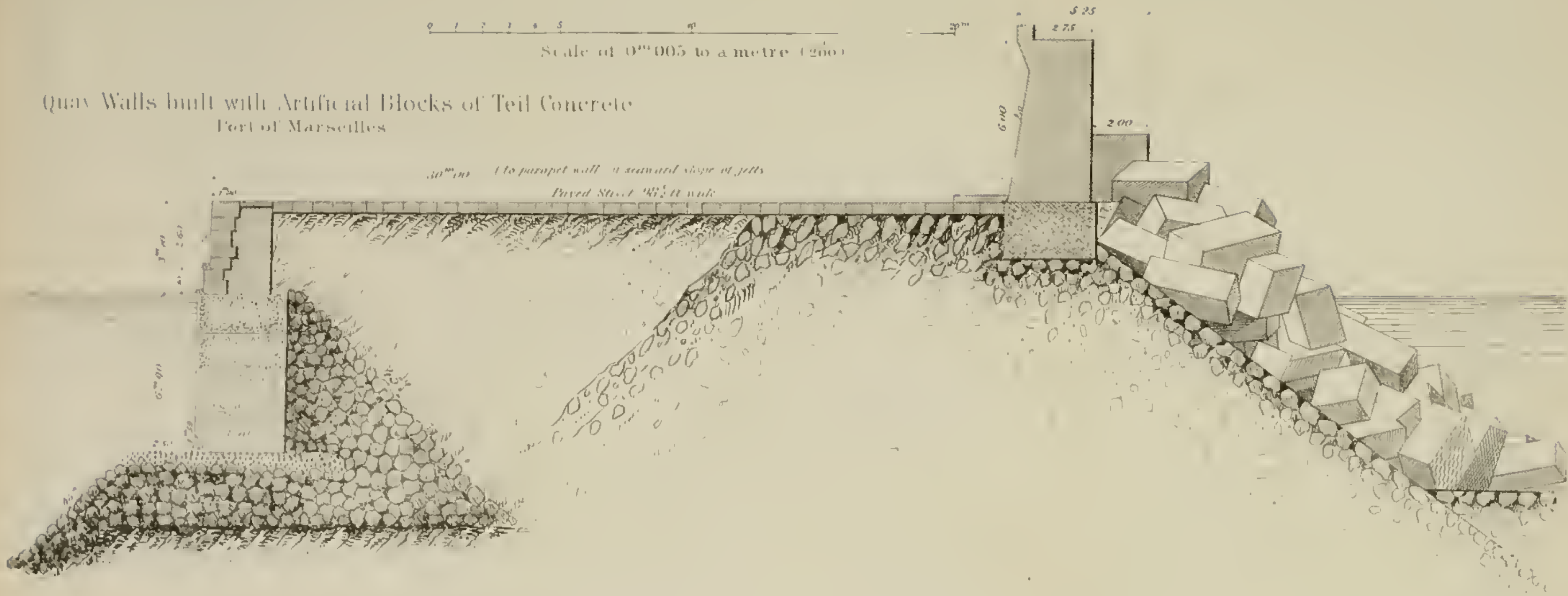


PLATE II

FABRICATION OF ARTIFICIAL BLOCKS

PLAN OF LA JOLIETTE YARD OF FABRICATION

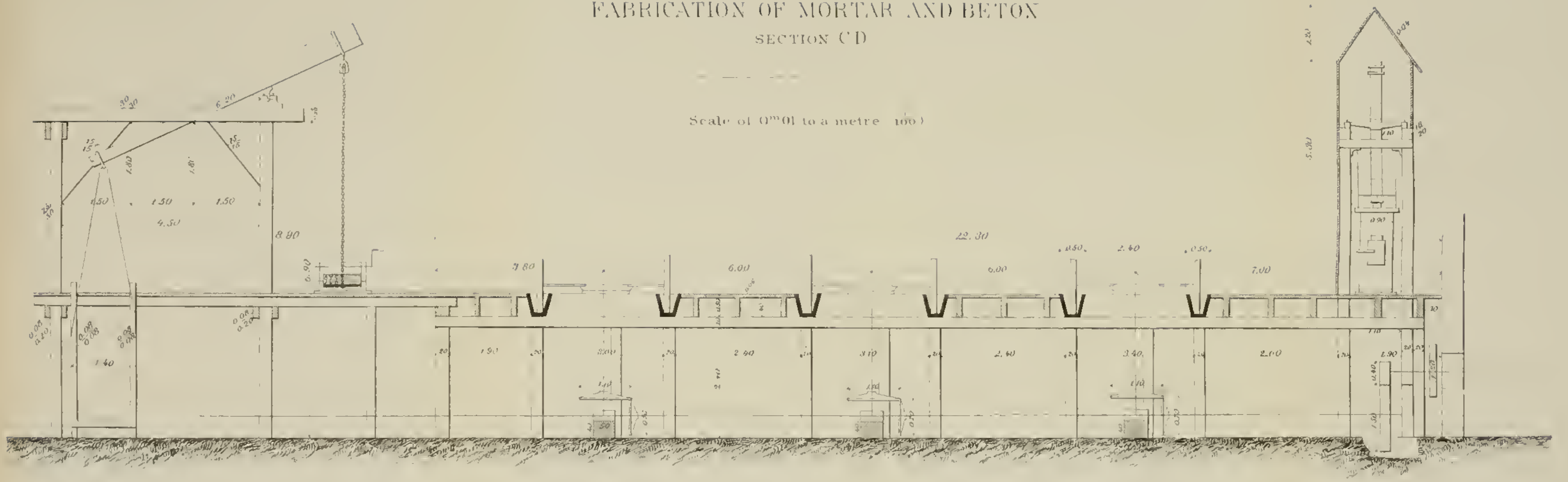
MARSEILLES

Scale 0^m 002 to a metre ($\frac{1}{500}$)

FABRICATION OF MORTAR AND BETON

SECTION CD

Scale of 0m01 to a metre (1/100)



FABRICATION OF MORTAR AND BETON

Plan of the upper floor of the Mortar Mills

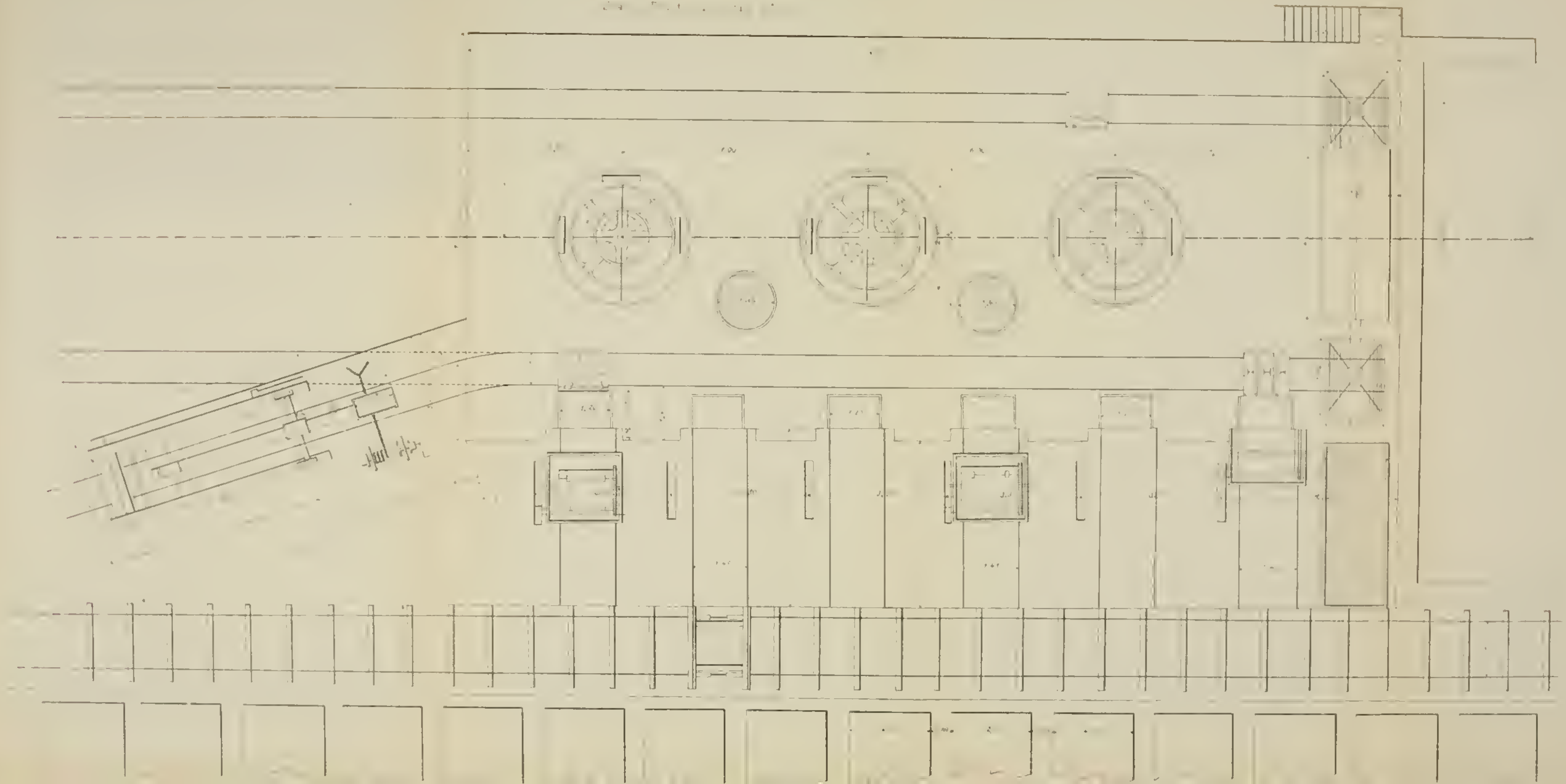
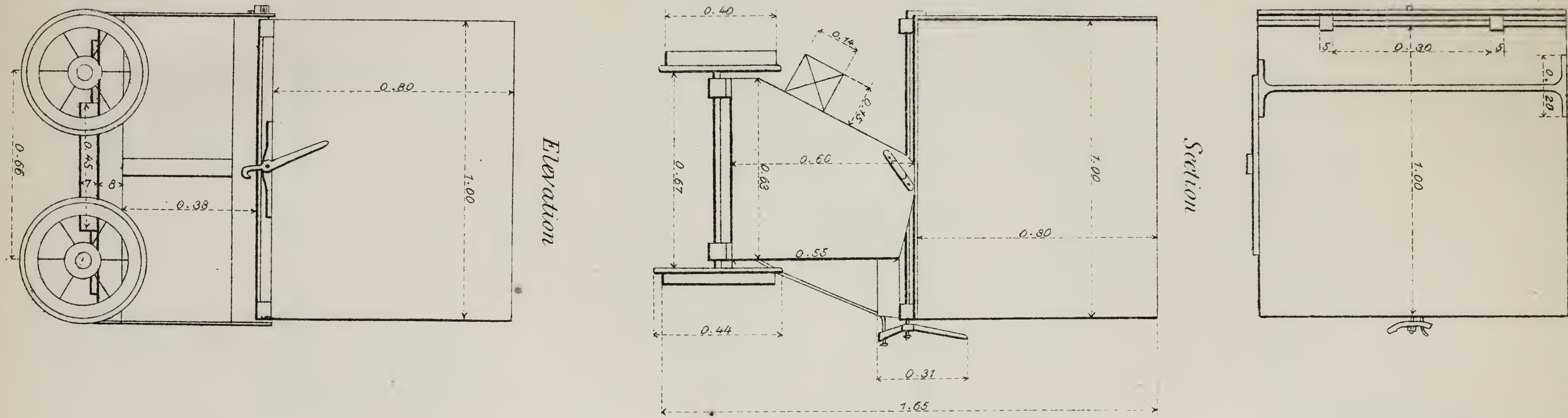


PLATE V

Sand Car.

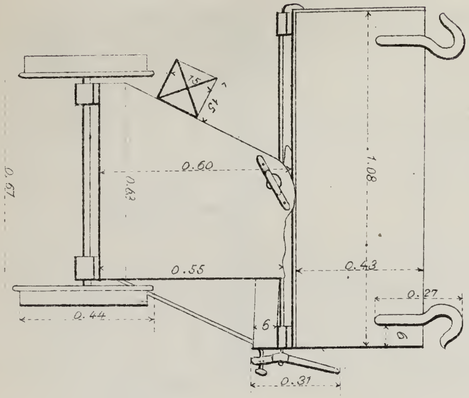


Scale 0m04 to a metre (1/25)

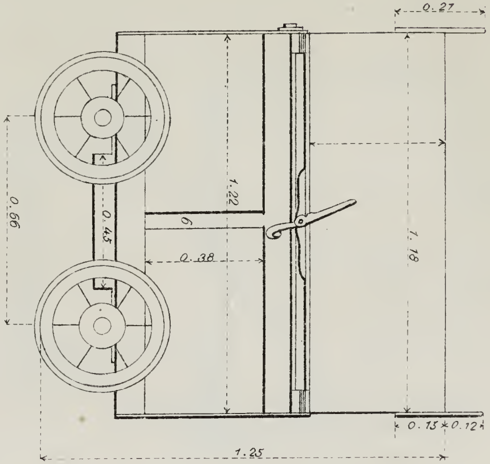
J. Bien, Lith.

PLATE VI

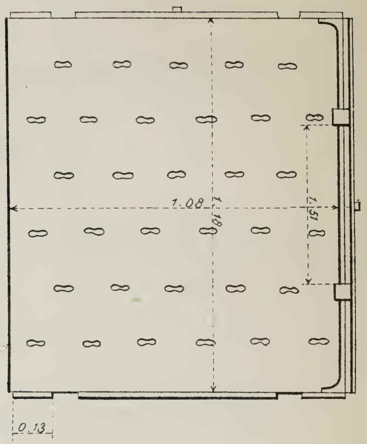
Pebble Car



Section



Elevation



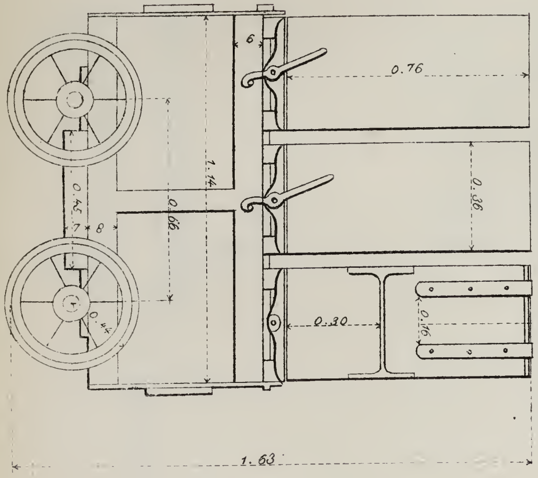
Plan

Scale $0^{m}.04$ to a metre ($\frac{1}{25}$)

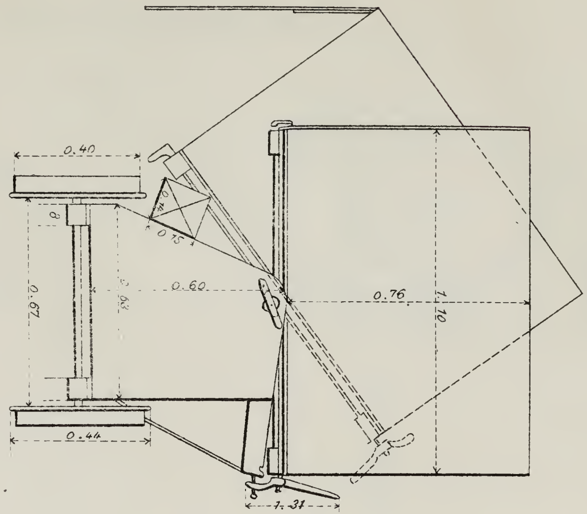
J. Bien, Lith

PLATE VII

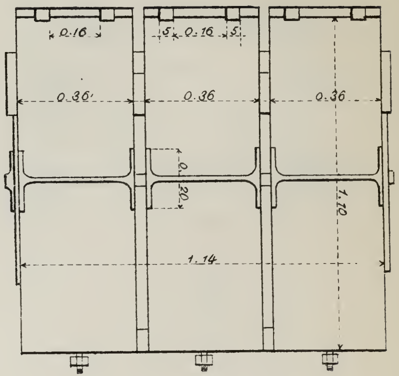
Mortar Car.



Elevation.



Section



Plan

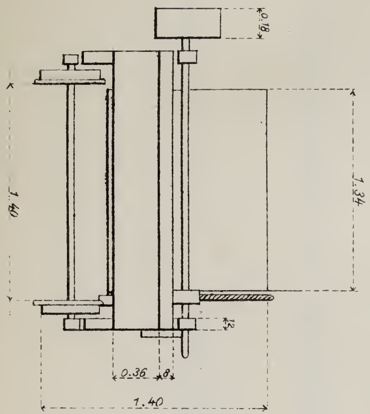
Scale 0.m04 to a metre (1/25)

J. Bien, Lith

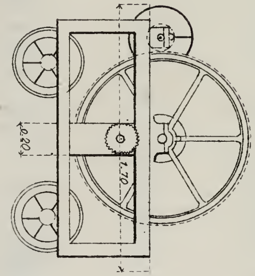
PLATE VIII

Mixing Cylinder for Beton.

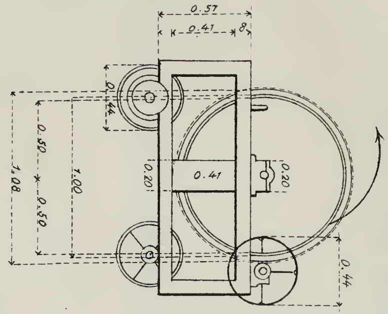
Scale of $0^{m}.02$ to a metre $(\frac{1}{50})$



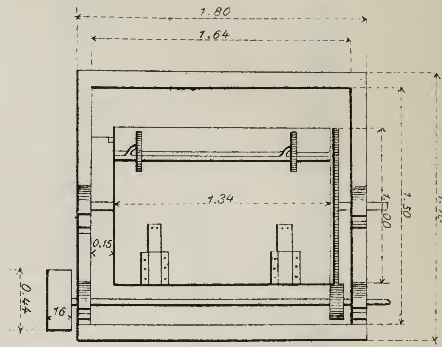
Side Elevation



Cross Section



End Elevation



Plan

J Bien, Lith.

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